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Applied Research Management

Abstract Bulletin

(Part I)

Abstracts 1-449 through 1-636

SEPTEMBER 1961

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Prepared for DEPUTY COMMANDER AEROSPACE SYSTEMS

AIR FORCE SYSTEMS COMMAND

UNITED STATES AIR FORCE

Inglewood, California



AEROSPACE CORPORATION

CONTRACT NO. AF 04(647)-930

Report No.
TDR-930(2701-01)TN-1
Part I, No. 3

APPLIED RESEARCH MANAGEMENT
ABSTRACT BULLETIN

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Page ii

ABSTRACT

Part I, No. 3 is a bibliography, with abstracts, from unclassified literature presented on the subject of Flight Vehicle Power. Selected references in the field of materials are also included. All references are to primary sources.

Approved by *K. B. Andrews*
K. B. Andrews
Literature Research Group

AEROSPACE CORPORATION
El Segundo, California

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I. FLIGHT VEHICLE POWER

SECTION A - GENERAL

- 1-449. **ADVANCED POWER SOURCES FOR COMMUNICATION ELECTRONICS.** David Linden. IRE Trans. on Military Electronics, vol. MIL 4, no. 4, Oct. 1960, p. 497-501.

Portable electrical power sources are being used in increasing numbers for a variety of applications on the ground and in outer space. The trend to miniaturization and transistorization has accelerated this practice. Chemical, nuclear, and solar energy are the three prime sources that are being used in power sources which will fulfill the new requirements. Each of these sources, in combination with new electrical conversion devices, has advantageous and unique characteristics which make it desirable for this application. The characteristics of various types of recently developed electrical power sources are described and compared, and data are presented which illustrate the best operating conditions for each item.

- 1-450. **BIBLIOGRAPHY ON UNCONVENTIONAL SOURCES OF ELECTRICAL POWER (SUPPLEMENT TO LTIS BIBLIOGRAPHY NO. 1).** John B. Forlini. Engineer Research and Development Labs., Fort Belvoir, Va., LTIS Bibliography no. 5. Jan. 1961. 50p. AD 248 615. A61-2444 (Supplement).

This bibliography represents a primary accumulation of current (1959-60) unclassified references resulting from a search of abstract journals, indexes, bibliographies, trade journals, and technical reports readily accessible.

1-451. DIFFUSION OF A MAGNETIC FIELD INTO A MOVING CONDUCTOR. John K. Oddson. Massachusetts Inst. of Tech., Cambridge. Research Lab. of Electronics, WADD TR 60-837. 3 Oct. 1960. 67p. illus. Contract: AF 33(616)-7624, Proj. no. 3145, Task no. 61098. 20 refs. A61-8334.

This is a study of the diffusion of a magnetic field into a copper slug as it traverses the air gap of a magnet. The results are discussed in terms of the magnetic Reynolds number of the system, a dimensionless parameter proportional to the ratio of a characteristic diffusion time, and the transit time through the field region. With the use of an approximate, single decay model of the diffusion process, the variation of magnetic flux is predicted and compared with the experimentally obtained response of search coils situated in the air gap. It is found that the peak flux change may be expressed in non-dimensional form as

$$\frac{\phi}{\phi P_{\max}} = R \cdot 1 - e^{-1/R}$$

where R is the appropriate magnetic Reynolds number and is proportional to, but considerably smaller than, the usual definition involving a critical conductor dimension as the characteristic length. The results of this study (cont.)

1-451. (Cont.)

have shown that an appreciable magnetic flux variation can occur if a conducting slug traverses the air gap of a magnet at a high magnetic Reynolds number. Associated with this flux variation is a corresponding energy transfer from the mechanical system driving the rotating disc to the electrical system, and vice versa, which may be utilized in several ways. The simplest of these would employ an arrangement similar to that used in these experiments, with a disc rotating through the air gap of a permanent magnet or dc electromagnet, and with output coils replacing the search coils. If a load were attached at the terminal of the output coils, the system would operate as an inductor type of alternator. A capacitor would be included in the output circuit to tune it to resonance at the driving frequency. An alternate arrangement in which the separate output coils are discarded and the load placed across the field windings themselves permits energy conversion with several configurations. The field may be supplied from either an ac or a dc source, and the use of a tuning capacitor is optional.

- 1-452. DIRECT ENERGY CONVERSION LITERATURE ABSTRACTS.
Mildred Benton. Naval Research Lab., Library Branch,
Technical Information Div. March 1961. 111p. A61-7778.

A collection of references from various sources covering the current literature on thermoelectricity, thermionic emission, photoelectric processes, magneto-hydrodynamics, electrochemical processes, energy storage, and energy sources.

- 1-453. ELECTRICAL CONTACTS IN SPACE ENVIRONMENT. AN
ANNOTATED BIBLIOGRAPHY. George E. Owens. Lockheed
Aircraft Corp. Missile Systems Div., Sunnyvale, Calif.,
Special Bibliography SB-61-23. May 1961. 84p. AD 258 424.
A61-5122.

This bibliography presents a survey of recent literature pertaining to electrical contacts in a space environment. It supports a laboratory investigation into the effects of strong ultraviolet radiation, hard vacuum (10^{-8} mm Hg or less), and low temperature (-50° to $+200^{\circ}$ F) upon moving electrical contacts operating at currents in the milliamperes-microampere range and at contact potentials up to a few millivolts. Because relatively little work in that environment has been reported, the bibliography includes references to work antecedent to the laboratory investigation, even though such work may not have been carried out within the specified range of conditions. References are arranged alphabetically by personal author in three categories: Books (28 refs), Reports (34 refs), and Journal Articles (107 refs). An index of secondary personal authors and corporate sources is provided, in addition to a subject index.

1-454 ENERGY CONVERSION SYSTEMS REFERENCE HANDBOOK.
Electro-Optical Systems, Inc., Pasadena, Calif., EOS
Report 390-Final, WADD TR 60-699. Sept. 1960. Contract:
AF 33(616)-6791, Proj. no. 4769, Task no. 61048. 9v.illus.
A61-6218.

- Volume I - General Systems Considerations, by W. R. Menetrey and J. H. Fisher.
- II - Solar-Thermal Energy Sources, by D. H. McClelland and C. W. Stephens.
 - III - Dynamic Thermal Converters, by C. W. Stephens, R. Spies, and W. R. Menetrey.
 - IV - Static Thermal Converters, by J. Blair and J. D. Burns.
 - V - Direct Solar Conversion, by W. Evans and W. R. Menetrey.
 - VI - Chemical Systems, by W. R. Menetrey and J. Chrisney.
 - VII - Heat Exchangers, by A. Haire and L. Hays.
 - VIII - Other Devices, by R. Wall, D. Erway, R. Spies, J. D. Burns, and D. McDowell.
 - IX - Solar System Design, by W. R. Menetrey.

1-455 HIGH-TEMPERATURE THERMAL CONDUCTIVITY MEASUREMENTS IN SEMICONDUCTORS. Robert G. Morris. Annual Summary Report. South Dakota School of Mines and Technology, Physics Dept., Rapid City. 1 July 1960. 20 p. illus.
Contract: NONr-2964(01). AD 239 000. 26 refs. A61-6213.

The objectives of the work are to measure the contact and bulk thermal conductivities of semiconductors, including Bi_2Te_3 and silicon, at temperatures above room temperature by means of the comparison method.

1-456. INVESTIGATION OF SILICON CONTROLLED RECTIFIERS FOR STATIC POWER CONVERSION. G. P. Underbrink. First Quarterly Progress Report, 1 July-30 Sept. 1960. Ling-Temco Electronics, Inc., Div. of Temco Electronics and Missiles Co., Dallas, Rept. no. T.E.R. 611.1901-A. 20 Feb. 1961. 81p. illus. Contract: DA-36-039-SC-85381. AD 257 828. 13 refs. A61-8449.

This report investigates an area of general research concerned with the application of the silicon-controlled rectifier to high-power conversion. The silicon-controlled rectifier is a logical choice for reliable, portable dc-to-ac static power inversion applications in excess of 1000 watts. Because of the problems resulting from its requirement for external circuit commutation, further study will be required to determine the most practical methods for this task. Unilateral series inverters are not suitable for high-power conversion. The symmetrical series inverter provides a sinusoidal output for limited load variation but is not suitable for high-power dc-ac conversion from low dc power supply voltages. The equations of this circuit are difficult to evaluate fully and experimental investigation of the circuit is anticipated. The SCR parallel inverter has been determined to be the best approach for high-power, low source voltage static inversion of the methods considered. This circuit is efficient, adaptable to various regulation techniques, and

(cont.)

1-456. (Cont.)

therefore can be designed to handle limited variable reactive loading with close regulation and tolerable distortion under widely variant input conditions. A 1000-watt power inverter prototype will be provided according to the contract specifications referenced in IV-3.0 of this report. The compound bridge inverter circuit is most effective for high-power, low-distortion polyphase power inversion where reasonably high dc supply voltage is available. The bridge circuit is especially useful for dc conversion where the dc supply voltage exceeds the voltage rating of the individual SCR. This circuit is not suitable for the low-voltage power inverter requirements of this program.

1-45,7. POWER SUPPLIES FOR SPACE VEHICLES. Nathan W. Snyder.
Astronautica Acta, vol. 6, no. 6, 1960, p. 272-310.

This dissertation discusses many of the problems associated with the development of the electric power sources for space vehicles. The following topics are discussed: power requirements for space; types of power systems (solar-photovoltaic, solar-thermoelectric and solar-thermionic, solar-dynamic engine system, solar-photoemission systems, solar regenerative fuel cells, nuclear-thermoelectric, nuclear-thermionic systems, nuclear-turbinelectric, nuclear-reciprocating engine system, chemical-thermoelectric system, radioisotope-thermionic or thermoelectric or dynamic engine system); weight considerations of space power systems; relation of ground system with space power systems; sources of energy (nuclear, solar energy); conversion of energy (thermal, photons, chemical, fission fragments); storage of energy (thermal energy, photons and nuclear particles, mechanical, electrical; special problems and special components (dissipation of energy in space, space environment, launching and orbiting forces and conditions, solar concentrators, orientation of solar cells, collectors and radiators, reliability, materials, re-entry problems); miscellaneous advantages and disadvantages.

1-45,8. POWER SUPPLIES FOR SPACE VEHICLES. Nathan W. Snyder.
In International Astronautical Congress, 11th, Stockholm, 1960, Proceedings. Vienna, Springer-Verlag, 1961, p. 688-714.
TL 787 1611.

It is becoming more apparent as space vehicles are developed for a variety of missions that a major limitation will be the availability of long life electric power sources. Such power is needed for communications packages, probes, navigation, weather surveillance, space, moon, or planet stations, instrumentation, guidance and control, scientific observation packages, devices for manned vehicles, and an assortment of servo-machinery powered by electricity. The amounts and duration of power required are discussed and summarized in a table. Power-weight ratios of current mechanisms and those that might reasonably be anticipated in the future are discussed. About the least currently available is 20-100 lb/kw for a reliable unit. It seems reasonable to expect that this may be brought as low as 1-5 lb/kw for a smaller plant and 10 lb/kw for a larger one. The bulk of the paper consists of a comprehensive survey of current knowledge and future developments in the fields involved in space power plants. These include sources of energy, means of power generation, energy conversion devices, energy storage, and reliability. Two appendices are included: I) Solar Cell Power Systems for Space Vehicles, and II) Some Data Concerning Radioisotopes for Power Supplies.

1-459. **SECONDARY POWER SOURCES CONCENTRATE ON SOLAR
UNITS.** Space Age News, vol. 4, no. 1, 10 July 1961, p. 30.

A short review of secondary power sources, of possibilities in using solar thermionic systems for various missiles and satellites, and of various organizations and companies engaged in the solar thermionic energy conversion systems.

1-460. **SOLAR-POWER SYSTEM TO BE TESTED SOON.** William Beller.
Missiles and Rockets, vol. 8, no. 23, 5 June 1961,
p. 22-23.

STEPS (Solar Thermionic Electric Power System) is being designed to operate with nickel-cadmium battery storage. Later versions may be adapted to use a thermal or fuel-cell storage system. The present version is being developed to work in a cycle of 55 min light, 35 min dark. The first system is sized to deliver 500 watts of continuous power in space environment. Later systems will develop 3-10 kw, if STEPS works as planned. Flight testing is expected by 1963. STEPS is being developed by General Electric under a contract with the Air Force.

- 1-461. SOLION INTEGRATION. G. T. Kemp and R. M. Hurd.
Research, vol. 14, no. 10, Oct. 1961, p. 382-7.

The time integral of electrical inputs can be obtained with a high degree of accuracy by use of electrochemical devices operating on the principles of coulometry and Faraday's laws of electrolysis. The family of electrochemical devices called Solions includes several types of integrators. Special design features, such as electrochemical and chemical diffusion barriers, permit retention of an integral for long time periods. Accuracy of the integration process is usually limited by the method of reading the integral, varying from less than 1/2% for some electrical readouts to upwards of 20% for visual estimation.

- 1-462. STUDY OF ELECTRICAL ENERGY CONVERSION SYSTEMS FOR FUTURE AIRCRAFT. H. H. Woodson and W. D. Jackson, eds.
Massachusetts Inst. of Tech., Cambridge. Electronic Systems Lab., WADD TR 60-148. 1 Feb. 1960. 129p. illus. Contract: AF 33(616)-3984, Proj. no. 8149, Task no. 61098. AD 243 592. 22 refs. A61-8372.

Energy-conversion studies in progress in the fields of magnetohydrodynamics and electromechanics are summarized, and work completed both in these fields and in thermoelectric and electrochemical energy conversion is briefly described. Work on magnetohydrodynamics of both liquids and gases is reported in Chapters II and III, respectively. Chapter II, Part A, deals with magnetohydrodynamic channel flow of incompressible fluids and includes a theoretical approach to turbulence, energy-conversion relations for Hartmann-type flow, and a description of an experimental investigation of velocity profiles. Chapter II, Part B, covering the work on liquid metal devices, gives further information on the development of a liquid metal dc transformer and a mercury arc oscillator for dc to ac conversion, and reports progress on the testing of liquid metal brushes for a homopolar motor. Chapter III discusses energy-conversion processes for compressible fluids in both steady and pulsed flows. The latter is illustrated by analysis of an eddy-current generator from both field and circuit viewpoints. A literature survey of work (cont.)

1-462. (Cont.)

on the time-dependent MHD problem is given; and experimental investigations, using a magnetically driven shock tube and a toothed-wheel machine, are reported. Further developments of microwave diagnostic equipment for a shock tube are described. Chapter IV is concerned with work on frequency-power formulas and their application to electromechanical energy conversion. Four basic types of frequency-power formulas are developed, using a state function approach; and their significance in system analysis is discussed both generally and with the aid of examples.

SECTION B - CHEMICAL SOURCES OF ENERGY

- 1-463. AUTOMATICALLY ACTIVATED ZINC SILVER OXIDE BATTERY.
Joseph J. Holecheck, Paul E. Streigle, et al. Quarterly
Progress Report No. 1, 1 July-30 Sept. 1960. Catalyst
Research Corp., Baltimore. 113p. illus. Contract:
DA-36-039-SC-85361. A61-8291.

A study has been initiated for the purpose of developing a chemically heated, automatic activation system for zinc-silver oxide batteries which will make them capable of 0.5 sec activation and operation throughout the range of -65 to 165°F with close voltage regulation. A literature search was made and studies were performed to obtain heat capacity, thermal conductivity, enthalpy, and other basic data pertinent to battery components. Included is the description of a copper block calorimeter used for the determination of heat capacities of basic battery materials. Calculations were made to determine the safe operating temperature of 31% potassium hydroxide electrolyte. A prototype heat exchanger, based on fundamental design criteria and theoretical requirements, was devised. Battery block equilibrium temperatures were calculated on the basis of enthalpy data. The heat adsorption rates of several important cell components were analyzed.

- 1-464. AUTOMATICALLY ACTIVATED ZINC SILVER OXIDE BATTERY.
Joseph J. Holechek, Paul E. Streigle, et al. Quarterly
Progress Report no. 2, 1 Oct. -31 Dec. 1960. Catalyst
Research Corp., Baltimore. 81p. illus. Contract:
DA-36-039-SC-85361. A61-8323.

During the second quarter, efforts were directed toward a continuance of the basic investigations such as the enthalpy of battery components, electrolyte requirement studies, and studies leading to the formulation of a chemical heat source. Prototype heat exchangers were tested and found to be a feasible means of rapidly heating rapidly flowing electrolytes. Battery block-electrolyte reservoir studies were made to determine the effect of equilibrium temperature and current density on activation. Gas generators or battery initiators were tested to determine whether temperatures in the range of -65 to 165°F would affect gas volume and rate of pressure. Several pieces of apparatus were constructed for use in these studies. A solenoid timer apparatus was designed and constructed for future electrolyte flow rate and temperature studies. In general, the results of this quarter have contributed significant basic information to the program and have continued to strengthen the feasibility of using a heat exchanger as a device for rapidly heating the automatically activated zinc-silver oxide battery.

1-465. CHARACTERISTICS OF OXYGEN ELECTRODES FOR
LOW-TEMPERATURE FUEL CELLS. I. A. Denison. Diamond
Ordnance Fuze Labs., Washington, D. C., Rept. no. TR-923.
24 Apr. 1961. 29p. illus. Contract: DA-5B51-02-004.
AD 255 944. 16 refs. A61-7201.

Available information has been assembled and evaluated on the methods of preparation and the physical and electrochemical characteristics of oxygen for electrodes for low-temperature fuel cells. Porous carbon and sintered metal cathodes have been considered with reference to methods of preparation, mode of operation, electrochemical characteristics, and other properties. Such electrodes are capable of operation in strongly alkaline electrolytes at current densities of several hundred amp/ft² for extended periods of time. Electrodes of noble metals, such as platinized platinum, are used in fuel cells in combination with an acidic or alkaline ion-exchange membrane electrolyte. Because of the slowness with which hydrogen peroxide is decomposed in acid media, fuel cells with acid electrolytes do not ordinarily operate at current densities greater than 20 amp/ft².

1-466. DESIGN AND CONSTRUCTION OF YARDNEY PRIMARY BATTERY
BA (X-R)/U. Martin Klein. Final Report, Jan. 1957-Sept. 1960..
Yardney Electric Corp., N. Y. Nov. 1960. 58p. illus.
Contract: DA-36-039-SC-73157, Proj. no. DA-3-18-03-043.
AD 252 250. A61-8303.

A series of batteries was built and tested to meet the Technical Requirements no. 57-ELS/D-3821. Owing to the marginal performance of the successful units and the difficulties encountered with the other units regarding heat-up period, capacity, 12-hr wet stand, and 5-min activation time, a complete redesign was deemed necessary. The completely redesigned battery consists of two separate sections, "A" and "B", which were built, based on previously determined cell parameters, and were subjected to a range of conditions covered by the specifications. Based on a 19-cell battery, the A Section unit cell voltage is 1.39-1.53 volts for 10 min of discharge at 120 amp. Based on a 20-cell battery, the B Section unit cell voltage is 1.40-1.53 volts at 60 amp and 1.15-1.53 volts at 160 and 220 amp. The final prototype battery was assembled and the two sections of the battery were tested under separate regimes. The evidence based on the test results leads to the conclusion that the battery can be produced to meet all aspects of the Technical Requirements (Appendix 1).

1-467. DESIGN STUDY OF LONG-DURATION, LOW-POWER, CHEMICALLY FUELED POWER SUPPLY WITH INTEGRATED THERMAL CONTROL. Interim Progress Report no. 6, 1 Oct. 1960-31 Jan. 1961. Sundstrand Aviation, Denver, Rept. no. CDRD-61:3007. 15 Feb. 1961. 92p. illus. Contract: AF 33(616)-6421. A61-3004.

A report for the design study of a long-duration, low-power, chemically fueled power supply for space vehicles is presented. This is the first interim report since the program was redirected from a closed cycle to a thermally integrated open cycle. The redirected program goals are to design, develop, and test an eight-shaft-hp FVPU system for a 300-hr mission fueled by a liquid hydrogen and liquid oxygen with a specific propellant consumption less than 1.5 lb/shaft hp hr. Shaft energy supplied to a direct driven alternator will be consumed by accessories and a load; this energy will then be returned to the turbine working fluid as cycle input. Preliminary cycle analysis has been completed to indicate the turbine geometry and configuration required. General cycle considerations have been included for evaluation of regenerator and catalytic reactor design criteria. Cryogenic tankage system storage and expulsion methods have been evaluated. Controls methods have been detailed with the plan of solution. Preliminary alternator tests have been completed and subsequent design modifications have been incorporated. Subcritical

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pressure storage and expulsion using capillary action of wicks have been tested for cryogene. Initial catalytic reactor tests have been run and results are presented. Development of the ground-run propellant tanks has been completed. The direct turbine-driven alternator rotating assembly design has been initiated both with gas bearings and an alternate ball bearing approach. The over-all program is in the transition period from the preliminary design phase to the final design and initial procurement stages.

I-468. DESIGN STUDY OF LONG-DURATION, LOW-POWER CHEMICALLY FUELED POWER SUPPLY WITH INTEGRATED THERMAL CONTROL. Interim Progress Report no. 8, 1 May-31 July 1961. Sundstrand Aviation, Denver. Div. of Sundstrand Corp., Rept. no. CDRD-61:3014. 15 Aug. 1961. 125p. illus. Contract: AF 33(616)-6421, Proj. no. 3145, task no. 30328. A61-8640.

An interim report for the design study of a long-duration, low-power, chemically fueled power supply for space vehicles is presented. This is the third such report since the program was redirected from a closed cycle to a thermally integrated open cycle. The redirected program goals are to design, develop, and test an eight-shaft-hp FVPU system for a 300-hr mission fueled by liquid hydrogen and liquid oxygen with a specific propellant consumption less than 1.5 lb/shaft hp hr. Shaft energy supplied to a direct-driven alternator will be consumed by accessories and a load; this energy will then be returned to the turbine working fluid as cycle heat input. Design features of the unit include: 300°F maximum cycle temperature, hydrogen gas-lubricated bearings, 48,000 rpm turbine direct driving a 3200 cps alternator (used as a loading device only), four-stage, single-disc, re-entry turbine wheel, and preheating and reheating energy derived from the turbine shaft power only.

I-469. DEVELOPMENT OF A SEMICONDUCTOR FILM-TYPE THERMOCOUPLE ENERGY CONVERTER. Quarterly Report no. 6, 1 Jan.-1 Apr. 1961. Minneapolis-Honeywell Regulator Co. Research Center, Hopkins, Minn. 17p. illus. Contract: DA-11-022-21X4902.501-ORD-3230. AD 258 075. A61-8260.

An oxide thermoelectric generator was constructed. The equipment was designed for a 100-volt output for at least 5 min; total volume was not to exceed 25 cu in. The generator constructed occupies 20 cu in.; it produces the required voltage with about 4-1/2 mw output. Curves showing output of the generator against various resistances are presented. Information gained should allow the construction of future generators of this type with the same voltage output in less than half of this space. The required voltage is obtained with only slightly more than 500°C differences in temperature between hot and cold ends. The generator establishes the usefulness of oxide thermoelectrics in applications where voltage at low current levels is required.

1-470. DEVELOPMENT OF ELECTRODE MATERIALS FOR FUEL CELLS. W. E. Parker, F. Rusinko, Jr., and R. W. Marek. Quarterly Report no. 2, 1 Oct. -31 Dec. 1960. Speer Carbon Co. Research Lab., Niagara Falls, N. Y., Rept. no. SCC-9. June 1959. 27p. illus. Contract: DA-36-039-SC-85356, Task no. 3G 18-03-001-01. AD 254 459. A61-7384.

Mixes have been made with a variety of raw materials. Samples prepared from these have been baked at two different baking rates to 900°C. Baked samples have been heat-treated further to 2750°C. Physical property measurements have been conducted on the baked and graphitized samples. Carbons with surface areas of 100-200 m²/g have been produced. These high area carbons are also found to contain a uniform pore size, concentrated at a pore diameter of approximately 2-4 microns.

1-471. ELECTROCHEMICAL FUEL CELLS. PART I. Kenneth D. Carroll. Lockheed Aircraft Corp., Missile Systems Div., Sunnyvale, Calif., Special Research Bibliography, SRB-60-5. Nov. 1960. 53p. AD 251 660. A61-4413, pt. 1.

A brief review of the more recent publications on electrochemical fuel cells, redox reactions, regenerative and hydrogen-oxygen fuel cell systems are given. This introductory bibliography is intended to acquaint one with this general area of study; especially, the rapid increase of reported investigations and applications during the past few years.

1-472. ENVIRONMENTAL TEST OF NICKEL-CADMIUM STORAGE BATTERIES. L. W. Kenyon. Ordnance Test Activity, Yuma, Ariz., Rept. no. DPS/OTA-42. OMS 5610.11.701, 5510.11.271. June 1961. 3p. illus. Contract: DA-598-09-004, 272-01-002. 9 refs. A61-8322.

Two HN- and six TN-type nickel-cadmium storage batteries were given environmental tests in test and facility vehicles over various terrain at the Yuma Test Station. Cell vent release plugs failed to function, but the durability of the battery should be considered satisfactory when the deficiencies are corrected.

1-473. FEASIBILITY STUDY ON HIGH-PERFORMANCE, SHORT-DURATION POWER BATTERIES. Quarterly Progress Report no. 1, 15 Dec. 1959-15 Mar. 1960. Union Carbide Consumer Products Co. Research Lab, Parma Ohio. Div. Of Union Carbide Corp. 9p. Contract: NOrd-18240. AD 235 245. A61-8277.

Chronopotentiometric analysis of sulfate, silicate, phosphate, and borate in the presence of varying amounts of CaO has shown that these materials behave similarly. The transition times decrease with increased oxide. The E_1/t values increased with increasing applied current, except in the case of the silicate. Whenever the added oxide was present in large excess, a second break appeared in the E vs t curve. This was identified with aluminate produced by reaction of the oxide with the alumina of the crucible. The reduction process for all four types of materials is very complex, even though the ultimate products are usually the free elements. A possible structural mechanism is offered to interpret the data obtained. The possibility of erroneous data due to contamination of the melt by silver from the porous quartz disk reference cell was eliminated by using a solid Vycor-sheathed unit for one series of experiments. Using this arrangement, a sulfate containing melt was reduced at voltages which were similar to those using the more accurate electrodes with porous disks (i.e., 0.45-0.88 volt, depending upon the current applied), and silver ions could not enter the solution in any way. Two

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experimental cells using calcium anodes, CuO cathodes, KCl-LiCl electrolyte and Kaolin clay as a separator produced an OCV of 2.54 volts, and on load an average of 1.47 volts at 0.15 amp/cm² drain at 600°C.

1-474. FEASIBILITY STUDY ON HIGH-PERFORMANCE, SHORT-DURATION POWER BATTERIES. Quarterly Progress Report no. 8, 15 Mar. -15 June 1960. Union Carbide Consumer Products Co. Research Lab., Parma, Ohio. Div. of Union Carbide Corp. 14p., illus. Contract: NOrd-18240. AD 239 882. A61-8265.

Chronopotentiometric analyses of sulfate, pyrosulfate, phosphate, pyrophosphate and the metaphosphate, with and without additional quantities of oxide, have been run. The data obtained from the tests involving pyrosulfate were found to be erratic due to the presence of bisulfate. Data obtained from pyrophosphate-containing melts showed two reactions taking place, the first at 0.9 volt and the second at 1.4 volts, against a silver-silver chloride reference electrode. When additional oxide was added to the melt three reactions occurred. The first of these was at 0.3 volt, the second at 0.85 volt and the third at 1.35 volts. The mechanism for the pyrophosphate reduction, in the presence of oxide, seems to involve the formation of a new species reducible at a lower potential than the pyro compound itself.

1-475. FEASIBILITY STUDY ON HIGH-PERFORMANCE, SHORT-DURATION POWER BATTERIES. Quarterly Technical Progress Report no. 9, 15 June 1960-15 Sept. 1960. Union Carbide Consumer Products Co. Research Lab., Parma, Ohio, Div. of Union Carbide Corp. 12p. Contract: NOrd-18240. AD 244 498. A61-4217.

Pure potassium pyrosulfate was prepared and used in chronopotentiometric studies of the pyrosulfate ion alone and with additional oxide present. Data were also obtained for various sulfur-containing materials, including sulfur itself, $\text{Na}_2\text{S}_2\text{O}_3$, $\text{Na}_2\text{S}_2\text{O}_4$, and K_2SO_3 . Similar studies were also carried out on potassium pyrophosphate and sodium trimetaphosphate with added magnesium oxide rather than calcium oxide. It was found that equimolar quantities of MgO and CaO with the pyrophosphate or the trimetaphosphate produced breaks in the voltage-time curve at the same potentials, but the transition times obtained with MgO were much smaller than those obtained with CaO . Attempts to obtain additional data on the carbonate system failed when it was found that the carbonate ion decomposes at 500°C to give CO_2 and carbon. Several tests were made on the purified melt to determine the value of the transition time for the residual impurities. It was found that these residuals were sufficiently low not to affect appreciably the other chronopotentiometric data obtained. Experimental cells using cold pressed mixtures of Kaolin clay
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and KCl-LiCl for electrolyte immobilization have performed satisfactorily. Porous alumina and magnesia structures are also being investigated as matrix materials for electrolyte immobilization.

1-476. FEASIBILITY STUDY ON HIGH-PERFORMANCE, SHORT-DURATION POWER BATTERIES. Quarterly Technical Progress Report no. 10, 15 Sept. -15 Dec. 1960. Union Carbide Consumer Products Co. Research Lab., Parma, Ohio, Div. of Union Carbide Corp. 12p. Contract: NOrd-18240. AD 251 817. A61-6805.

The chronopotentiometric work was concluded with some studies of $K_2B_4O_7$, B_2O_3 and $K_2S_2O_7$ with various quantities of added oxide. Equipment for measuring diffusion coefficients of phosphates and sulfates in molten $KClLiCl$ is being assembled and tested. A number of test cells involving Sb_2O_3 , CuO , borates, silicates, and phosphates as depolarizers have been made and evaluated. Kaolin clay, which is an alumino-silicate, and which has previously been used as a separator, acted as a depolarizer. When kaolin clay was replaced by fused MgO as the separator, cell output increased more than threefold in some cases.

1-477. FEASIBILITY STUDY ON HIGH-PERFORMANCE, SHORT-DURATION POWER BATTERIES. Quarterly Progress Report no. 11, 15 Dec. 1960-15 Mar. 1961. Union Carbide Consumer Products Co., Parma, Ohio. Div. of Union Carbide Corp. 15p. illus. Contract: NOrd-18240. AD 254 151. A61-6215.

The diffusion coefficient of silver was determined in $KCl-LiCl$ at $600^\circ C$ and found to agree within 10% of a value obtained by D. M. Gruen of the Argonne National Laboratory. An appreciable number of test cells involving Sb_2O_3 , CuO , phosphates, and sulfates has been evaluated. In the case of Sb_2O_3 , the maximum service obtained was 132 watt-hrs/lb. For CuO the maximum was 177 watt-hrs/lb. When sodium metaphosphate was used as the depolarizer, the maximum obtained was 226 watt-hrs/lb. The sulfate depolarized cells have reached a maximum of 136 watt-hrs/lb.

1-478. FLAT CELL MAGNESIUM DRY CELL BATTERIES. F. A. Keller. Semiannual Progress Report no. 3, 1 Apr. -1 Oct. 1960. Bright Star Industries, Clifton, N.J. 12p. Contract: DA-36-039-SC-78231, Task no. 3-18-03-701. AD 251 012. A61-8469.

Results to date indicate that a zinc-plated magnesium anode can be made that will not lead to the formation of a high-resistant film when the conductive adhesive is applied to it. If this fact is substantiated from future experiments, it will allow us to study other factors in making magnesium flat cells. While the problem of maintaining low contact resistance is investigated further, an attempt will be made to find a more economical solution.

1-479. FLAT CELL MAGNESIUM DRY CELL BATTERIES. F. A. Keller. Semiannual Progress Report no. 4, 1 Oct. 1960-1 Apr. 1961. Bright Star Industries, Clifton, N.J. 12p. Contract: DA-36-039-SC-78231. A61-8324.

Attempts were made to fabricate a zinc-plated magnesium duplex electrode, which would prevent formation of a high-resistance junction when conductive adhesive is applied. Zinc plating one side of the magnesium anode to provide a passive surface was unsuccessful because of inability to prevent the zinc from pitting the magnesium. Use of a high-purity conductive adhesive proved unsatisfactory due to formation of a high-resistance junction. The magnesium electrode is not malleable enough for zinc cladding process. A Dow Chemical Company conductive lacquer showed promise in coating the duplex electrode.

1-480. FUEL CELL AND ITS RELATED TECHNOLOGY. I. CORRELATION BETWEEN MAGNETIC SUSCEPTIBILITY AND CATALYTIC ACTIVITY OF ELECTRODE. Ju Chin Chu and S. M. Hu. Bimonthly Progress Report no. 4, 16 Sept. - 15 Nov. 1960. Brooklyn Polytechnic Inst., Chemical Engineering Dept., 30p. illus. Contract: DA-44-009-ENG-4586. AD 252 102. 39 refs. A61-5667.

The theory of magnetism was outlined with a short account for the molecular field theory of paramagnetism and domain theory of ferromagnetism. Due discussion was presented on ferromagnetism in thin films as a necessary prior knowledge in experimentation with thin films. Phenomena associated with thin films are the uncertainty in the decrease of magnetization, transition of the magnetism type and thickness limitation for the ferromagnetism. Contamination, notably oxygen, of the ferromagnetic films affects markedly the magnetic properties. A new experimental technique was proposed to replace the one presented before. This device was aimed at avoiding air contamination and at having a greater certainty of measuring accuracy. The apparatus used is a modification of the one used by Neugebauer in the measurement of saturation magnetization of thin films below 100 angstroms. The apparatus body is detachable through Teflon-gasketed joints. Connection is provided for mounting on the vacuum deposition setup. This experimental
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method is based on the principle of torque magnetometer. A torsion wire also serves as a lead to potentiometer for emf measurement. Dynamic emf will be measured for various current densities. The inadequacy of an open circuit potential of a catalytic electrode is discussed.

1-481. FUEL CELL AND ITS RELATED TECHNOLOGY. I.
CORRELATION BETWEEN MAGNETIC SUSCEPTIBILITY AND
CATALYTIC ACTIVITY OF ELECTRODE. Ju Chin Chu and
S.M. Hu. Bimonthly Progress Report no. 7, 16 Nov. 1960-
15 Jan. 1961. Brooklyn Polytechnic Inst. Chemical Engineer-
ing Dept. 30p. illus. Contract: DA-44-009-ENG-4586.
AD 252 103. A61-5670.

A revised method is described in which the thin metallic films used as a catalyst are vacuum deposited outside the sample cell. In this method the deposition of thin films is to be carried out in an ordinary bell-jar vacuum deposition system with minor mechanical modification. A small thin-walled glass container with a neoprene O-ring packing is used to keep the sample from air contamination. This container is then broken with a plunger in the sample cell. A preliminary study of the feasibility of use of the torque magnetometer was made. The result shows that the sensitivity of this method is extremely high. Due to the inadequate use of copper wire as torsion wire, an irreversible stress-strain relation was observed. Contamination, possibly oxygen, on the Fe-Ni sample film was responsible for the failure in detecting the change of magnetic susceptibility before and after the film was exposed to either ammonia or formaldehyde vapor. For our purpose of investigating the transient behavior of the catalytic surface, the modified Guoy's method was
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adopted. This method measures magnetic susceptibility in a closed system, and uses an Ainsworth Model RV-AU-1 automatic recording vacuum balance. By this method, it is possible to study transient phenomena. The mechanical details and theoretical basis of this method are fully described in this report. The installation of the accessories and controls to the electromagnet has been completed. A number of tests have been made to check if all specifications have been met.

- 1-482. FUEL CELL AND ITS RELATED TECHNOLOGY. I. CORRELATION BETWEEN MAGNETIC SUSCEPTIBILITY AND CATALYTIC ACTIVITY OF ELECTRODE. Ju Chin Chu and S.M. Hu. Bimonthly Progress Report no. 10, 16 Jan. - 15 Mar. 1961. Brooklyn Polytechnic Inst., Chemical Engineering Dept. 14p. Contract: DA-44-009-ENG-4586. AD 255 732. A61-7711.

In this report rate equations for chemisorption are analyzed. The transient of magnetic susceptibility and fraction of unoccupied active sites are shown to be related to one another. Rate coefficients for chemisorption are expressed in terms of the magnetic susceptibility change. Necessary information is analyzed and the method of interpretation of data is described in detail. In addition a scheme of factorial experiment design is presented.

- 1-483. FUEL CELL AND ITS RELATED TECHNOLOGY. II. CORRELATION BETWEEN INFRARED SPECTRUM AND CATALYTIC ACTIVITY OF ELECTRODE. Ju Chin Chu and W. S. Yu. Bimonthly Progress Report no. 2, 16 July - 15 Sept. 1960. Brooklyn Polytechnic Inst., Chemical Engineering Dept. 14p. illus. Contract: DA-44-009-ENG-4586. AD 252 104. 20 refs. A61-5665.

The objective of this work is to develop a quantitative relation between the catalytic activity and reaction kinetics on the surface of the fuel cell electrode. For the catalytic activity, the half-cell potential is used as a practical index. The reaction kinetics is analyzed by infrared spectra from the chemisorption of the gases by the catalytic surface on the electrode. A sound correlation between the infrared spectra and half-cell potential can lead to a successful development for a practical fuel cell employing hydrocarbon and other cheaper fuels. The relevant work in the previous literature has been critically reviewed. It was found that the successful work had been mostly with the absorption infrared technique. The application of the reflection technique was quite recent and no work was reported for a system of three co-existing phases, i.e., electrode surface, gas, and liquid electrolyte. The in situ fuel electrode is housed in a high vacuum system for the catalyst deposition on the electrode surface. Provision should be made to introduce

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fuel gas and electrolyte into the system. The correlation between the half cell potential and infrared spectra can be obtained by using the same fuel gas and different catalysts on the same electrode under a given operating condition. The relative order of the catalytic activities can thus be determined. For the further application, the interpretation of the infrared spectra of the chemisorbed molecules will determine the actual structure of these molecules and the effect of poisons on the catalyst.

1-484. FUEL CELL AND ITS RELATED TECHNOLOGY. II. CORRELATION BETWEEN INFRARED SPECTRUM AND CATALYTIC ACTIVITY OF ELECTRODE. Ju Chin Chu and W. S. Yu. Bimonthly Progress Report no. 5, 16 Sept. - 15 Nov. 1960. Brooklyn Polytechnic Inst., Chemical Engineering Dept. 12p. Contract: DA-44-009-ENG-4586. AD 252 105. A61-5668.

An infrared optical system for reflection has been designed as an attachment to Perkin-Elmer Model 21 Double Beam Spectrophotometer. This system is to be mounted between the exit of the source and the entrance of the monochromator. The infrared energy from the source will be reflected back to the entrance slit of the monochromator and has the same image as the energy directly passes the sample area. Within such an optical system, the catalyst for the fuel cell electrode is in the form of a mirror surface which gives characteristic peak spectrum upon the absorption of infrared energy in the presence of surface reaction.

- 1-485. FUEL CELL AND ITS RELATED TECHNOLOGY. II. CORRELATION BETWEEN INFRARED SPECTRUM AND CATALYTIC ACTIVITY OF ELECTRODE. Ju Chin Chu and W.S. Yu. Bimonthly Progress Report no. 10, 16 Dec. 1960-15 Jan. 1961. Brooklyn Polytechnic Inst., Dept. of Chemical Engineering. 11p. illus. Contract: DA-44-009-ENG-4586. AD 252-106. A61-5671.

An outline about fuel gas cell is given. A design of an in situ type sample cell has been described. An experimental technique has been proposed for recording the infrared spectrum during the chemisorption of fuels upon a metallic catalyst surface and also for measuring the half-cell potential as soon as the infrared spectrum is obtained. The details of instrumentation are considered. The Perkin-Elmer double-beam infrared spectrophotometer Model 21 will be modified according to the alternate optical system. The design of this system and the suitable sample cell is given in this report. Some details of experimental techniques are described.

- 1-486. FUEL CELL AND ITS RELATED TECHNOLOGY. II. CORRELATION BETWEEN INFRARED SPECTRUM AND CATALYTIC ACTIVITY OF ELECTRODE. Ju Chin Chu and W.S. Yu. Bimonthly Progress Report no. 11, 16 Jan. - 15 Mar. 1961. Brooklyn Polytechnic Inst., Dept. of Chemical Engineering. 7p. Contract: DA-44-009-ENG-4586. DA-44-009-ENG-4586. AD 255 733. A61-7710.

Because of the large number of mirrors involved in the reflection technique, a transmission technique will be considered in this report. The method of preparation of the sample is also described in this report. The measurement of chemisorbed gas spectrums has been previously described. Two main experimental difficulties have to be overcome in this work. First, the adsorbed substance must be present in sufficient quantity for its adsorption spectrum to be observable. Second, the scatter radiation loss should be reduced to as low a value as possible.

- 1-487. FUEL CELL AND ITS RELATED TECHNOLOGY. III. CORRELATION BETWEEN SURFACE CONDUCTIVITY AND CATALYTIC ACTIVITY OF ELECTRODE. Ju Chin Chu and Leonard M. Salzarulo. Bimonthly Progress Report no. 3, 16 July-15 Sept. 1960. Brooklyn Polytechnic Inst., Dept. of Chemical Engineering. 13p. illus. Contract: DA-44-009-ENG-4586. AD 252 107. 13 refs. A61-5666.

The objective of this investigation is to measure the surface conductivity and to correlate the latter with the activity of various catalysts. Frequency response approach for the investigation of cell kinetics is also proposed in this report. The basic theory and possible advantage are briefly discussed. Conductivity measurement alone gives information about the product of mobility and carrier concentration. Hall effect determines these quantities separately. The so-called Hall coefficient can be evaluated if a current is passed through the materials at right angles to a magnetic field. Both the frequency response and Hall effect techniques, although promising, are beyond the scope of the current contract. Detailed investigation by these methods is not planned at this time.

- 1-488. FUEL CELL AND ITS RELATED TECHNOLOGY. III. CORRELATION BETWEEN SURFACE CONDUCTIVITY AND CATALYTIC ACTIVITY OF ELECTRODE. Ju Chin Chu and Leonard M. Salzarulo. Bimonthly Progress Report no. 6, 16 Sept. -15 Nov. 1960. Brooklyn Polytechnic Inst., Dept. of Chemical Engineering. 6p. Contract: DA-44-009-ENG-4586. AD 252 108. A61-5669.

The change of surface conductivity on the electrode is determined prior to the introduction of the liquid electrolyte into the cell. The half-cell potential will be measured with the proper provision to eliminate the polarization at the standard electrode. A method is proposed for the measurement of surface conductivity during the chemisorption of gas upon a metallic catalyst. The measurement is accomplished by using the catalyst surface as one plate of a cylindrical capacitor. Since the conductivity of each of the plates of a capacitor contributes to the capacity loss, any change in surface conductivity will cause a change in capacity loss. Therefore, a measurement of capacity loss can be used as an indirect measure of surface conductivity. Apparatus for measuring half-cell potential and electrical conductivity has been designed. A calomel electrode will be used to measure half-cell potential for the fuel electrode. The proposed experiments are discussed.

- 1-489. FUEL CELL AND ITS RELATED TECHNOLOGY. III. CORRELATION BETWEEN SURFACE CONDUCTIVITY AND CATALYTIC ACTIVITY OF ELECTRODE. Ju Chin Chu and Leonard M. Salzarulo. Bimonthly Progress Report no. 9, 16 Nov. 1960-15 Jan. 1961. Brooklyn Polytechnic Inst., Dept. of Chemical Engineering. 17p. Contract: DA-44-009-ENG-4586. AD 252 109. A61-5672.

During the operation of a fuel cell, the observed potential is lower than the theoretical or equilibrium potential. This is due to polarization which occurs during current flow. The various types of polarization which occur in a fuel cell are discussed. Among these are activation polarization, mass transport polarization, gas transport polarization, and electrolyte concentration polarization. It is the objective of our work to determine the effect of the catalyst upon the activation polarization. Quantitative expressions are developed for various polarizations for the data interpretation. A fuel cell constructed of PVC has been designed and fabricated. The cell contains two stuffing boxes, one in the top flange and one in the bottom of the cell. A sintered alumina tube impregnated with the metal catalyst under study is positioned between the stuffing boxes. Conductivity measurements, in the absence of electrolyte, and half-cell potentials, in the presence of electrolyte, can be made.

- 1-490. FUEL CELL CATALYSTS. A. P. Hauerl. Quarterly Report no. 1, 1 July-30 Sept. 1960. Engelhard Industries, Inc., Newark, N.J. Research and Development Div. 31 Oct. 1960. 32p. illus. Contract: DA-36-039-SC-85043, Task no. 3G18-03-001-01. AD 254 010. A61-8316.

A one-year program of research on electrode catalysts for fuel cells has been taken up. In this application organic liquid fuels are to be oxidized with oxygen at ordinary temperatures, up to 50°C. Complete oxidation of the fuel to carbon dioxide and water is required under expulsion from the system of the carbon dioxide formed. The electrolyte of the cell, therefore, must be acidic. The first part of the program accordingly is concerned with research on oxygen electrodes operable in acid medium. Measurements are reported on oxygen potentials obtained with precious metal catalysts in sulfuric acid. Measurements of hydrogen peroxide decomposition rates made on the same catalysts do not correlate with the values of the oxygen potentials. The possibility of such a correlation was of interest since rates of formation and decomposition of peroxide might be determining for the value of the electrode potential.

1-491 FUEL CELL CATALYSTS. Quarterly Report no. 2, 1 Oct. -31 Dec. 1960. Engelhard Industries, Inc., Newark, N.J. Research and Development Div. 40p. illus. Contract: DA-36-039-SC-85043, Task no. 3G18-03-001-01. AD 254 011. A61-6196.

A number of precious metals and combinations of precious metals deposited on carbon powder have been examined as catalysts for the oxygen electrode in sulfuric acid. Platinum on carbon appears to be the most active catalyst, the efficiency increasing with increasing platinum content. Optimum performance was obtained with a catalyst consisting of 30% platinum on carbon which is superior to unsupported platinum black. Electrolytes in the acid-to-neutral range have been investigated as media for the oxygen electrode catalyst; in general, strong acid media appear preferable. Certain sources of error have become evident in employing sine wave pulse generators for elimination of ohmic polarization and in employing half cells for evaluating electrode performance in ion exchange membrane cells.

1-492. HIGH-CAPACITY MAGNESIUM BATTERIES. G. S. Lozier and R. J. Ryan. Quarterly Progress Report no. 3, 1 Dec. 1960-28 Feb. 1961. Radio Corporation of America. Somerville, N.J. 16p. Contract: DA-36-039-SC-85340, Proj. no. 3G-18-03-001. A61-8733.

Further development of $\text{Mg/Mg}(\text{ClO}_4)_2/\text{HgO}$ reserve cells is summarized. Optimum performance was obtained using a silver-plated, expanded copper cathode grid, and mechanically blended cathode mix. The initial voltage discharge characteristic was improved by the addition of silver II oxide to the cathode mix. A comparison is given between the magnesium cupric oxide and mercuric oxide reserve cells. Magnesium anode efficiency data are presented for various alloys at 10 ma/cm^2 as a function of temperature, and as a function of time off on intermittent service. Capacity, delayed action, and impedance shelf-life studies for $\text{Mg/Mg}(\text{ClO}_4)_2\text{MnO}_2$ and $\text{Mg/Mg}(\text{ClO}_4)_2\text{CuO}$ 'AA' size dry cells are summarized to six (6) months storage.

- 1-493. HIGH-CAPACITY VENTED NICKEL-CADMIUM BATTERIES.
Arthur Fleischer, Edward C. Kopper, et al. Quarterly Progress
Report no. 1, 30 Nov. 1959-29 Feb. 1960. Thomas A. Edison
Industries, Storage Battery Div., McGraw-Edison Co. West
Orange, N. J. 56p. illus. Contract: DA-36-039-SC-84555.
AD 237 393. A61-8275.

The task of manufacturing six types of high-capacity nickel-cadmium cells varying in capacity from 3.5-36 amp-hrs was set up into three phases: experimental, design, and manufacture. For the experimental phase, Type 4 cell, 14 amp-hrs in capacity, was selected for the confirmation of the proposed design and processing factors. The required increase of 15-20% in rated capacity over presently available nickel-cadmium cells in plastic jars is expected to be attained by the determination in the experimental program of the effect of cobalt addition to the active material, the effect of lithium hydroxide addition to the electrolyte, the effect of plate thickness, the selection of a suitable separator and separator thickness, and by a suitable choice of positive and negative plate thicknesses fixing the active material ratio.

- 1-494. HIGH-CAPACITY VENTED NICKEL-CADMIUM CELLS.
Arthur Fleischer, Edward C. Kopper, et al. Quarterly Progress
Report no. 2, 1 Mar. -31 May 1960. Electric Storage Battery
Co. West Orange, N. J. Nickel Alkaline Battery Div.
29 July 1960. 79p. illus. Contract: DA-36-039-SC-84555.
AD 242 920. A61-4230.

All cells having 15-plate and 11-plate elements failed to meet the capacity requirement for the Type SC4 cell at the 5-hr rate at -40°F. All cells met the capacity requirement for the Type SC4 cell on discharge at the 15-min (3C) rate at room temperature.

1-495. HIGH-ENERGY BATTERIES. Quarterly Progress Report nos. 6 and 7, 15 Sept. 1959-14 Mar. 1960. Eastman Kodak Co., Rochester, N. Y., Rept. no. EK/ARD ED-313. 29 July 1960. 68p. illus. Contract: NOrd-18249. AD 241 208. A61-4434.

The specific conductivity and the density of sulfur solutions in ammonia were measured at subzero temperatures. It was found that sulfur solutions are moderately good conductors; peak conductivities being roughly half the values found for good conductors such as NH_4SCN in ammonia. Many electrolyte solutions were surveyed in Mg/C cells. By far the best results were obtained with electrolytes containing either KSCN or NH_4SCN and either S or N_4S_4 . The latter permit sustained discharge without excessive cathode polarization. KSCN is preferred to NH_4SCN since magnesium corrodes at a lower rate in the more neutral solution. An investigation of the cathode process was begun. No clear conclusion has been reached as to the primary electrochemical process at the cathode. Work on the effect of using various metals and carbon as the cathode material has shown that the highest short-circuit currents are achieved with noble metals such as Ag, Pt or Pd as cathodes in cells with KSCN-S- NH_3 electrolyte. Data on discharge rates at practical voltage levels have not yet been obtained. On the basis of all work with sulfur systems to date an output of 5 watt-hrs/lb of cell structure has been attained. It is anticipated that this will be improved by structural modifications. This value
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will be degraded by a factor of 3 to 5 in a complete battery. A method for preparing N_4S_4 of high purity has been developed in order to supply limited amounts for this program. To date it has not been possible to find an outside source which is willing to even quote on supplying N_4S_4 in small quantities.

1-496. HIGH-ENERGY BATTERIES. V.M. Bryant, Jr. Quarterly Progress Report no. 8, 15 Mar. -14 June 1960. Eastman Kodak Co., Rochester, N.Y., Rept. no. EK/ARD ED-480. 2 Sept. 1960. 22p. illus. Contract: NOrd-18249. AD 242 546. A61-4435.

During the period covered by this progress report, a marked improvement in cathode current efficiency and cell output was obtained by passing the sulfur in solution through a porous cathode. Experimentation did not substantiate the hypothesis that hydrogen evolution is the principal electrochemical process at high ratios of electrolysis, although hydrogen is evolved at the cathode in KSCN or KClO_4 electrolyte cells. In addition, a program was established for further investigation into the cathode reaction.

1-497. HIGH-ENERGY BATTERIES. V.M. Bryant, Jr. Quarterly Report no. 9, 15 June-14 Sept. 1960. Eastman Kodak Co., Rochester, N.Y., Rept. no. EK/ARD ED-522. 15 Nov. 1960. 43p. illus. Contract: NOrd-18249. AD 246 864. 8 refs. A61-8318.

An analysis of the thermodynamics of the magnesium-sulfur cell at 25°C was made by extrapolation from thermodynamic data available in the literature. It is likely that magnesium sulfide is highly soluble in ammonia, so that the cell reaction cannot be described by the simple equation $\text{Mg} + \text{S} \rightarrow \text{MgS}(\text{c})$. The possibility that magnesium amide may form in a neutral electrolyte was considered. The data used and the assumptions made are sufficiently imprecise that a definite conclusion could not be reached on this point. Experimentally, the discharge of cells, in which a solution of sulfur and KSCN in ammonia was forced through the cathode at a known rate, was carried out at cathode current efficiencies of 50% or better based on the theoretical capacity of the sulfur fed to the cell, and at energy outputs as large as 250 watt-hrs/lb of MgS formed (at Kodak) and 195 watt-hrs/lb of MgS (at Corson). Inclusion of the cathode material, the ammonia and KSCN used with the sulfur, and an assumed anode thickness of 0.010 in. reduced the output of the Kodak cell to 4.9 watt-hrs/lb of cell proper (anode, cathode, and electrolyte). Higher output is projected by use of more concentrated sulfur solutions and
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lighter cathodes. Corson has proposed that recirculation of the spent electrolyte to dissolve additional sulfur should be beneficial. An investigation by Corson into the effect of the method of solution preparation on cell performance shows that different solutions are produced by following various procedures.

1-498. HIGH-ENERGY BATTERIES. V.M. Bryant, Jr. Quarterly Report no. 10, 15 Sept. -14 Dec. 1960. Eastman Kodak Co., Rochester, N. Y. Rept. no. EK/ARD ED-576. 13 Mar. 1961. 97p. illus. Contract: NOrd-18249. AD 252 650. A61-8319.

Data on the performance of Mg/S cells of the force-feed type using sulfur in ammonia solution and on Mg/S:C flat cells using dry sulfur-carbon cathodes are compared. The voltage of the cells with dry sulfur is much greater than that of those using dissolved sulfur. For 15-min discharge periods, the flat cells can deliver more than 20 watt-hrs/lb of cell proper with good voltage regulation. A battery delivering 9-12 watt-hrs/lb seems feasible at this time. On the other hand, the force-feed cells have not attained much above 12 watt-hrs/lb of cell proper. Corson has prepared a survey of the literature on sulfur, the highlights of which are included. They are investigating improvement of performance by recirculation of electrolyte through dry sulfur, using either a closed-circuit circulation scheme or an oscillating motion of the electrolyte. Data for estimating the output of such cells are not yet available.

1-499. HIGH-ENERGY BATTERIES. V.M. Bryant, Jr. Quarterly Report no. 11, 15 Dec. 1960-14 Mar. 1961. Eastman Kodak Co., Rochester, N.Y., Rept. no. EK/ARD ED-633. 15p. Contract: NOrd-18249. AD 253 790. A61-6187.

Significant progress was made during the quarter, both in obtaining better energy density from cells and in understanding the factors that may limit performance of the magnesium-sulfur couple. Flat cells that delivered nearly 50 watt-hrs/lb of cell proper (i.e., cell components without external packaging) were operated at Kodak for 15 min, with excellent voltage regulation for more than 10 min. At Corson, reciprocating flow cells with solid sulfur behind the cathode produced more than 50 watt-hrs/lb of cell proper, with slightly poorer regulation. These energy densities are more than double those which had been achieved three months ago. The improvement resulted from the discovery that silver is not sufficiently inert for use in solid sulfur and that surfaces such as platinum, rhodium, lead, titanium, or nickel are much better. In addition, passing electrolyte through solid sulfur behind the cathode, and modifications in sulfur-carbon ratios, cell structure, and electrolyte composition were beneficial. The factors limiting cell performance appear to be: 1) a requirement for large amounts of ammonia to solvate the cations at the anode, and 2) the formation of polysulfide ions at the cathode which move away from the electron-transfer surface before they can be reduced further.

1-500. INDUSTRIAL PREPAREDNESS MEASURES ON SOLID ELECTROLYTE BATTERY. S.B. Williams and A.G. Ceely. Quarterly Report no. 9, 1 Jan. -31 Mar. 1961. Sprague Electrical Co., North Adams, Mass. 13p. Contract: DA-36-039-SC-81251. AD 256 314. A61-8315.

A number of preproduction batteries were tested for open-circuit voltage at plus 125°F and minus 25°F. The batteries were placed in a cold box at -25°F for a minimum of two hours, followed by a charge of 0.05 mfd-200 volt Mylar capacitor through a 50-megohm resistor. The complete test consists of 20 consecutive duty cycles at the end of which the circuit is left open for two min and then closed. The same procedure was followed at plus 125°F. Further, the evaluation of electrical properties of 155-volt batteries which had been subjected to several of the long-term environmental conditions was carried out. The batteries evaluated were stored a minimum of 30 days and, in most cases, at least 90 days at room temperature. Following this conditioning, some of the units were stored at 165°F for 30 days. The batteries were then capacitor duty cycled under one of three storage conditions: room temperature, -27°F, and +125°F. Experimental results showed the following:
1) Five batteries were run after being stored a minimum 30 days at room temperature. In all cases, no difficulty was encountered during cycling, although storage time for several of the units was well in excess of 90 days.
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2) After being stored 90 days at room temperature, three batteries were duty cycled at 125°F. Again, there was no difficulty in attaining 90V on the capacitor. 3) Six batteries were duty cycled at -27°F following 90 days of storage at room temperature. Five of the six batteries passed the cycling requirement. 4) Duty cycling requirements were also met by five batteries which were cycled at -27°F after conditioning consisting of 90 days at room temperature storage followed by storage for 30 days at 165°F. Based on the results in this report, there should be no further difficulties in the manufacturing and completion of the preproduction samples.

1-501. INDUSTRIAL PREPAREDNESS STUDY OF SYNTHETIC MANGANESE DIOXIDE IN MASS PRODUCTION OF MILITARY DRY BATTERIES. H.K. Bishop. Quarterly Progress Report no. 13, 28 July-28 Oct. 1960. Union Carbide Consumer Products Co., Div. of Union Carbide Corp., N.Y. 9p. Contract: DA-36-039-SC-75946. AD 250 310. A61-8299.

In this study the properties of two new chemically prepared depolarizers produced by the Manganese Chemicals Corporation and the American Potash and Chemical Corporation were investigated. These depolarizers were evaluated in BA-30, BA-270/U, and BA-279/U batteries which were tested for compliance with MIL-B-18B requirements. Recently available test results from preproduction sample batteries containing above depolarizers indicate that they will satisfactorily meet MIL-B-18B requirements after storage for 3 months at 70°F (21°C) and 113°F (45°C). The very important delayed capacity test results will not be available for some months and a complete evaluation of above depolarizers cannot be made without them.

1-502. INVESTIGATION OF NEW SOLAR REGENERATIVE FUEL CELL SYSTEMS. Frank A. Ludwig. Final Report, 30 Nov. 1959-30 Nov. 1960. Electro-Optical Systems, Inc., Pasadena, Calif., Rept. no. EOS 400-Final. 168p. Contract: DA-36-039-SC-85270, Proj. no. 3A99-09-001, Task no. 3A99-09-001-04. AD 255 463. A61-7193.

The purpose of this contract is 1) to perform a general analysis, permitting evaluation of the theoretical efficiency of any regenerative fuel cells 2) to conduct a survey of promising compounds for thermally regenerative fuel cells, both from thermodynamic and from kinetics standpoint, and 3) to undertake experimental development of new concepts for regenerative fuel cells. A kinetic analysis was performed to indicate any chemical dissociation rate problems which may be encountered for systems which looked promising from a thermodynamic standpoint. Electrochemical kinetic parameters (which must be experimentally determined) are also discussed from the standpoint of how they relate to the dissociation kinetics. The general thermodynamic criterion F/H was chosen for the evaluation of chemical compounds. Of those compounds found attractive from a thermodynamic standpoint, only a few remained attractive after kinetic analysis. Also, a brief analysis of the efficiency of photochemically regenerative fuel cells was made. The experimental data of the H_2SO_4 vaporization-condensation fuel cell indicates good (cont.)

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closed cycle operation at current densities of 20 ma/cm^2 at 0.3 volt. The main problem remaining is to build a proposed design which would eliminate thermal conduction losses. Several problems remaining in the thermodynamic analysis include extending the analysis quantitatively to include all 12 of the models proposed and special cases thereof.

- 1-503. INVESTIGATION OF SILVER OXIDE PRIMARY BATTERIES. P. Ruetschi. Quarterly Report no. 4, 1 Mar. -31 May 1960, and 1 June-30 June 1960. Electric Storage Battery Co., Carl F. Norberg Research Center, Yardley, Penna. 12p. illus. Contract: DA-36-039-SC-78319, Proj. no. 3G18-03-001. AD 246 968. A61-4461.

Non-reserve primary AgO-Zn cells were assembled employing the high capacity electroformed AgO plates developed under this contract. The electrodes were tested in a multi-plate construction of the ESB type S-7.5 size cell. A majority of the multi-plate cells assembled and tested were made with a 6 negative-5 positive assembly. Cells discharged at the 2 amp continuous rate normally delivered 15 to 16 amp-hrs, which is equivalent to an energy output of 60-64 watt-hrs/lb at an average 1.5 volts closed circuit potential. Chemical and electroformed AgO materials were also evaluated in a button-type designated 625-DT. A higher cell operating voltage and greater energy output were obtained by the incorporation of a special conductive matrix in the AgO pellet electrode.

- 1-504. INVESTIGATIONS LEADING TO THE DEVELOPMENT OF IMPROVED SEALED NICKEL-CADMIUM BATTERIES. Quarterly Progress Report 1 July-30 Sept. 1960. Gulton Industries, Inc., Metuchen, N. J. Alkaline Battery Div. 27p. illus. Contract: DA-36-039-SC-85390. A61-5243.

Work has been started in the following areas: 1) hermetic seal, 2) separators, and 3) uniformity of cells. A ceramic seal developed by the Materials and Ceramics Division of Gulton Industries will be subjected to leakage tests upon arrival of a leak detector. Twenty separators were wetted with electrolyte and subjected to an acceleration of 25 g for 2 min. The results of this test are tabulated in the report. Some separators can absorb up to 10 times their own weight of electrolyte, and retain a goodly portion after acceleration. The equipment for determining Tafel slopes and oxygen evolution rates of the positive plates was made operative. Preliminary work on a standard Gulton plate indicates good reproducibility of data. The data are not interpreted because this is only the beginning of the work. The electrode used has a theoretical capacity of 0.6AH. At the 10 hr discharge rate it yields 0.4AH; 0.6AH at a slower rate. The electrodes for the continuation of the experiments were impregnated.

1-505. INVESTIGATIVE STUDY RELATING TO FUEL CELLS. Quarterly
Quarterly Report no. 2, 25 July-25 Oct. 1960. California
Research Corp., Richmond, Calif. 30 Dec. 1960. 70p. illus.
Contract: DA-49-186-502-ORD-929. AD 249 123. 15 refs.
A61-3076.

The objective of this contract is the clarification of the detailed chemical reaction mechanisms and kinetics of fuel half-cell electrodes. Petroleum-derivable fuels, such as propane, propene, isobutane, and cyclopentane, platinized or palladized carbon or nickel electrodes, and aqueous alkaline or acid electrolytes, are typical of the elements to be studied. The electrochemical oxidation of methanol was studied using the chronopotentiometric method (voltammetry at controlled current). Evidence was found in basic solution that a dissociative adsorption of methanol or methylate ion occurs on palladium- or platinum-plated porous carbon electrodes which probably produces adsorbed hydrogen atoms and the corresponding adsorbed dehydrogenated methanol or methylate species. It was found that platinum was a better catalyst than palladium for the electrochemical oxidation of methanol in basic solution. It appears that the palladium catalyst is poisoned by an intermediate reaction product, probably adsorbed hydrogen, at reasonably high current densities; i. e., 5 ma/cm². The platinum catalyst is not poisoned in our experiments under equivalent conditions. Methanol fuel cell
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product studies were carried out using sodium hydroxide electrolyte and platinized porous carbon electrodes. Formate is the principal product. Therefore, the oxidation of formate to carbonate must be considered as the limiting reaction in the development of practical basic electrolyte methanol fuel cells. It was also shown that formaldehyde is formed at the anode, and in small amounts leaves the vicinity of the electrode and builds up in the electrolyte. This occurs to a greater extent at 53°C than at 24°C at the same current density. In acid electrolytes, preliminary results indicate that formaldehyde is oxidized more slowly than either methanol or formic acid. Therefore, at this time the oxidation of formaldehyde to formic acid appears to be the reaction limiting the development of a practical acid electrolyte methanol fuel cell. Methylcyclohexane appears to become electrochemically active at temperatures above 80°C in basic solution. At 80-82°C, the electrochemical oxidation is very slow. Current-voltage scans of methanol, formaldehyde, and formate have been observed at several potential scan rates in basic, aqueous solutions. In Tafel regions and regions of kinetic complication, either a pre-electrode solution reaction or a slow adsorption is found. The electrochemical reaction, which limits current in the Tafel region (most negative potentials), increases in rate as the potential scans in a positive direction. The peak current increases linearly with fuel concentration and
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also with increasing pH. The latter effect on formate has not been studied. Rate constants at the reversible potentials have been calculated at several pH values for methanol and for a single pH value for formaldehyde and for formate ion. The $(1-\alpha)n_a$ values have also been determined. The rate constants corrected to the same potential show that formaldehyde oxidizes faster than methanol, which in turn is faster than formate in basic solutions. Thus, when methanol is oxidized in the vicinity of -0.8 volts in 1 molar KOH ($E_{\text{reversible}} = -0.834$), the product is mainly formate. The formation and reduction of platinum oxide have been investigated, and their effects on the oxidation of methanol and formaldehyde have been demonstrated. Anodic current due to hydrogen oxidation, especially in the Tafel region for formaldehyde, has been investigated. Some indirect evidence has been gained showing that formaldehyde probably does not oxidize through the catalytic formation of hydrogen molecules. Double layer charging currents on a number of electrodes at several scan rates are shown. Two alternative mechanisms can be proposed for these oxidations. In the first, the kinetic complication arises from a solution reaction involving hydroxide ions. The adsorption step with C-H bond breaking is presumed to be rapid. In the second mechanism, the hydroxide attack speeds an otherwise slow adsorption. In the study of the dissociative adsorption of fuels at catalytic surfaces,
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difficulties had been experienced with containing the absorbant in the adsorption cell. This has been solved by sealing sintered glass plates into both leads to the cell. Excessive adsorption of hydrocarbon vapors by stopcock lubricant has been eliminated by using a new design of greaseless high-vacuum valve.

1-506. INVESTIGATIVE STUDY RELATING TO FUEL CELLS.
Quarterly Report no. 3, 26 Oct. 1960-25 Jan. 1961. California Research Corp., Richmond, Calif. 15 Mar. 1961. 91p. illus.
Contract: DA-49-186-502-ORD-929. AD 254 312. 18 refs.
A61-7011.

A fuel cell product study with methanol in acid electrolyte showed that low steady-state concentrations of formaldehyde and formic acid were established in the anolyte. The over-all voltage of the methanol-oxygen fuel cell was found to be lower in acid than in base electrolyte due to poorer performance of the methanol half-cell in acid than in base. Product data obtained from a methanol fuel cell using base electrolyte and operating intermittently under load indicated that formaldehyde can be converted to other products by a non-electrochemical process at the platinum electrode. The anodic oxidation of methanol, formaldehyde, and formic acid at platinized-platinum electrodes was studied using the techniques of voltammetry at controlled current. Some chronopotentiometric runs on methanol in various concentrations of base were made to measure the rate constant for the pre-electrochemical attack of base on methanol. The results of these studies using the platinized-nickel ball electrode followed approximately the theoretical plots of $i\tau^{1/2}$ vs i for a kinetically limited process.

1-507. LIGHTWEIGHT HIGH-DRAIN ZINC-SILVER OXIDE BATTERY.
Gilbert R. Snyder. Diamond Ordnance Fuze Labs., Washington, D. C., Rept. no. TR-859. 22 Aug. 1960. 27p. illus.
Contract: DA-5N06-01-010. AD 243 692. A61-8373.

The PS-503 reserve-type power supply has been designed for use in a compact electronic device. The electrically initiated, zinc-silver oxide power supply will function over the temperature range of -40 to $+160^{\circ}\text{F}$ with a current density of approximately 0.5 amp/in.^2 of projected electrode area. This miniaturized power supply was made possible by earlier work described in DOFL Report TR-560. The battery consists of two voltage sections: a 1.4-volt section and a 6.7-volt section. It is activated by a pressure-vacuum system without auxiliary heat or heating devices.

1-508. MILITARY APPLICATION OF SEALED, SINTERED PLATE, RECHARGEABLE NICKEL-CADMIUM BATTERIES. Signal Corps Logistics Evaluation Group, Philadelphia, Rept. no. SIGSU-A8. June 1960. 38p. AD 246 317. A61-8431.

Sealed, sintered plate nickel-cadmium dry cells have advantages over zinc cells. Nickel-cadmium cells are still in an early stage of development and can be much improved. Cost of the initial cells procured will be high because the conversion of old, or procurement of new, equipment will be included. When total production is achieved, costs will level off so that the capacity-use-cost ratio of the new cells will be very favorable. In addition, they will offer unlimited shelf life and improved cold weather capacities over zinc cells. Sealed, sintered plate nickel-cadmium cells offer cold weather and cost advantages over zinc cells justifying the placing of additional development contracts and procurement of battery packs for testing. Some disadvantages of nickel-cadmium cells might limit their use to other than combat, except in cold weather. When the problems of battery packs, testers, chargers, power sources, and personnel to handle the charging have been resolved, sealed, rechargeable nickel-cadmium cells could provide considerable savings to the Government. The arguments for and against their use in combat would have to be considered and a decision reached at responsible levels.

1-509. ORGANIC FUEL CELL SYSTEM. Gerald A. Baum. Resin Research Labs., Inc., Newark, N.J., WADC TR 59-780. Nov. 1960. 74p. illus. Contract: AF 33(616)-6399, Proj. no. 3145, Task no. 60813-2. AD 254 076. A61-6190.

The purpose of this investigation was to determine the feasibility of developing an organic fuel cell system for use as an electrical power source in future USAF space applications. Initial results showed that: 1) liquid cathode fuels were preferred for systems utilizing magnesium as the anode fuel, and 2) mononitro compounds were preferred to di and trinitro compounds. Subsequent results indicated that: 1) due to problems of both a theoretical and practical nature, neither magnesium nor aluminum could be used as anode materials despite their theoretically attractive electrochemical potentials and coulombic capacities, and 2) formidable problems existed in regard to efficient utilization of nitro compounds being used as cathode fuels. A theoretical investigation indicated the inapplicability of a regeneration system for the foregoing cathode fuels.

1-510. PAPERLINED ZINC DRY CELLS AND BATTERIES. Final Technical Report, Mar. 1957-Oct. 1960. Bright Star Industries, Clifton, N.J. 39p. Contract: DA-36-039-SC-73207. AD 252 288. A61-8304.

The purpose of this contract was to obtain initial 113°F and 507 RH and delayed performance data on various sizes of dry cells and batteries, using the Methocel MB-1 coated-paper-type separator in zinc can anodes, with electrolytic manganese dioxide and acetylene black for the cathode. Discharge data (initial, high temperature and delayed) were obtained on the seven battery types listed in accordance with the technical requirements of this contract. Summaries of these data are presented.

1-511. PRELIMINARY CALCULATIONS OF THE REGENERATION AND RECOVERY REQUIREMENTS FOR A BROMIDE-BROMINE ELECTRODE FOR A REDOX FUEL CELL. William E. Reneke. Florida. Univ., Gainesville. Engineering and Industrial Experiment Station. 15 June 1960. 22p. Contract: DAI-49-186-502-ORD(P)-860. AD 243 517. 8 refs. A61-8282.

All calculations in this design are based on isothermal operation at either 20 or 25°C. No data were available at other temperatures. The regeneration tower requirements are based on Posner's paper dealing with the air regeneration of bromine with a nitrogen oxide catalyst. This paper did not give sufficient data for an exact design procedure. Based on his statement that the same results were obtained with the flow and batch apparatus, the column was sized from the residence time required to complete the same degree of regeneration in a batch operation. It was assumed that the tower had 68% free volume (standard for 1 in. Raschig ring packing) and that 50% of this volume was vapor space. The design calculations were all based on the requirements of a fuel cell with a rated power output of 10 kw. Rated power output: 10 kw. Regeneration tower: height of tower--41.2 ft; diameter of tower--1.5 ft; liquid flow rate--3.5 gal/min; gas flow rate--342 lb/hr ft², Bromine recovery (water scrubber): height of tower - 18.6 ft; diameter of (cont.)

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tower - 1 ft; liquid flow rate - 20.7 gal/min; gas flow rate - 342 lb/hr ft².
Total power requirements for regeneration and recovery: 1.25 kw.

1-512. PRIMARY CELLS UTILIZING ORGANIC COMPOUNDS AS THE ACTIVE COMPONENTS. E. F. Uhler, R. J. Ryan, et al. Eighth Quarterly and Final Report, 15 June 1958-30 Oct. 1960. Radio Corp. of America. Somerville, N.J. 1 Nov. 1960. 120p. illus. Contract: DA-36-039-SC-78048. AD 257 341. A61-8313.

A detailed discussion of the performance of the magnesium-meta-dinitrobenzene cell is presented. A summary of the capacity, shelf-life, delayed action, impedance, and temperature-dependence data for the magnesium-meta-dinitrobenzene cell is presented. Shelf-life and capacity data on a few other nitro organic compounds augment this section. A discussion of the roles of carbon and water in the m-dinitrobenzene cathode and the effect of magnesium efficiency upon cell performance is presented. An evaluation of various cell configurations (round and flat) to provide design criteria for optimum cell structures are presented. The design of a practical flat cell is described. A magnesium-m-dinitrobenzene dry cell with a capacity of 90 watt-hrs/lb is described. A brief review of the theory concerning the effect of group type and position in a molecule and its effect on cathode potential is presented for the aromatic nitro and nitroalkane compounds. Its extension to heterocyclic nitro compounds and organic anode materials is

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described. The more important classes of organic anode materials, hydrazine, and organic cathode materials, nitropyridines and nitrofurans are discussed in greater detail. Recommendations for future work and conclusions in both areas are given.

1-513. REDOX FUEL CELLS. L. G. Austin. Quarterly Progress Report no. 2, 1 June-1 Sept. 1960. Pennsylvania State Univ., University Park. Coll. of Mineral Industries. Dept. of Fuel Technology. 3p. Contract: DA-49-186-502-ORD-917. AD 243 589. A61-8271.

An essential part of a redox fuel cell is the fuel regenerator, where an ion is reduced to a more negative ion by means of a chemical fuel. The problem is to determine, for specified ion pairs and carbonaceous fuels, the volume of fuel regenerator required to maintain current output within the cell. Information on the kinetics of the regeneration process is required, in order to calculate volume versus current requirements at various operating temperatures. Tasks undertaken: 1) to delineate the theory of the relation between kinetic parameters, volume and current; 2) to obtain relevant kinetic data from the literature; 3) to design and construct apparatus for measuring the kinetics of the reactions between ion pairs and carbonaceous fuels; 4) to devise suitable analytical techniques for the ion pairs and fuels used; and 5) to determine the relevant kinetic information. The reactor described in the first quarterly progress report is being constructed to operate at temperatures from 0-100°C. After consideration of various rapid analytical techniques such as colouimetry, infrared and ultra-violet light absorptivity, and polarography, it was concluded that polarographic analysis
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might be suitably convenient. A simple instrument has been built and calibrated for the titanium ion pair and formic acid. However, it has not yet been tested as to whether the substances will mutually interfere in mixtures.

1-514. REDOX FUEL CELLS. L. G. Austin. Quarterly Progress Report no. 3, 1 Sept. -1 Dec. 1960. Pennsylvania State Univ., University Park. Coll. of Mineral Industries. Dept. of Fuel Technology. 4p. Contract: DA-49-186-502-ORD-917. AD 249 227. A61-3269.

The reactor for kinetic studies from 0-100°C is almost complete and will be in operation in the next quarter. It has not been possible to find a suitable glass lined autoclave to operate up to 250°C. Fisher titanous chloride (laboratory chemical grade) solution has been obtained and standardized for total titanium. Several gravimetric methods were tried and were found to give contaminated precipitates. The method finally used was cold precipitation with 6% Cupferron solution. The precipitate was bulky but easily filterable and washable. It was ignited and weighed as TiO_2 . A satisfactory method for the analysis of formic acid in strong acid (HCl , H_2SO_4) solutions has not been found.

- 1-515. REDOX FUEL CELLS. Quarterly Progress Report no. 4, 1 Dec. 1960-1 Mar. 1961. Pennsylvania State Univ., University Park. Mineral Industries Experiment Station. 7p.
Contract: DA-49-186-502-ORD-917. AD 253 598. A61-6197.

An essential part of a redox fuel cell is the fuel regenerator, where an ion is reduced to a more negative ion by means of a chemical fuel. The problem is to determine, for specified ion pairs and carbonaceous fuels, the volume of fuel regenerator required to maintain current output within the cell. Information on the kinetics of the regeneration process is required, in order to calculate volume versus current requirements at various operating temperatures. Studies of the reduction of TiO^{2+} to Ti^{3+} have been made in the range 25° - 80°C . To prevent hydrolysis and precipitation of TiO_2 , it was found necessary to use hydrochloric acid concentrations of four normal. At these concentrations, formic acid and formaldehyde have not given significant reduction in the temperature range employed. Platinum impregnated active carbons suspended in the reactant solutions have not produced any measurable reaction.

- 1-516. RESEARCH INVESTIGATIONS LEADING TO THE DEVELOPMENT AND EVALUATION OF A CADMIUM - SILVER OXIDE BATTERY HAVING A HERMETICALLY SEALED CONSTRUCTION. J.K. Wilson. Quarterly Progress Report no. 1, 1 July-30 Sept. 1960. Eagle-Picher Co., Joplin, Mo. 18p. illus. Contract: DA-36-039-SC-85370. AD 249 625.
A61-4481.

Exploratory work and a number of general tests were performed during this quarter in order to obtain data that would lead to the development of a rechargeable, cadmium-silver oxide cell having a hermetically sealed construction. Various types of open and closed separators as well as a combination of the two were evaluated in order that both long cycle life as well as the capability of being overcharged could be designed into the cells. Test results indicate that a combination of separators including cellophane must be used in order to promote long cycle life. A preliminary study of the effects of electrolyte volume and concentration as well as positive-to-negative capacity ratio was made to determine the effects of these variables on cycle life and the capability of being overcharged. The data observed indicate that a very fine balance of electrolyte-to-core weight, as well as positive-to-negative capacity, is necessary in order to obtain optimum cell characteristics.

1-517. RESEARCH INVESTIGATIONS LEADING TO THE DEVELOPMENT AND EVALUATION OF A CADMIUM-SILVER OXIDE BATTERY HAVING A HERMETICALLY SEALED CONSTRUCTION.

J.K. Wilson. Quarterly Progress Report no. 2, 1 Oct. - 31 Dec. 1960. Eagle-Picher Co., Joplin, Mo. 49p. illus. Contract: DA-36-039-SC-85370, Proj. no. 3G18-03-001-02. AD 254 493. A61-7040.

The purpose of this contract is to develop and evaluate a hermetically sealed, readily reproduced, rechargeable cadmium-silver oxide battery having a high level of reliability and performance. During the second quarter, 700 shallow cycles have been obtained from cadmium-silver oxide sealed cells. The data obtained indicate that 0.040 amp is the maximum continuous overcharge rate that can be applied to the cells of the present design. Cell containers and covers were designed for use in the final design sample cells to be delivered at the end of the contract.

1-518. RESEARCH INVESTIGATIONS LEADING TO THE DEVELOPMENT AND EVALUATION OF A CADMIUM-SILVER OXIDE BATTERY HAVING A HERMETICALLY SEALED CONSTRUCTION. J.K. Wilson. Quarterly Progress Report no. 3, 1 Jan. -31 Mar. 1961. Eagle-Picher Co. Joplin, Mo. 15p. illus. Contract: DA-36-039-SC-85370, Proj. no. 3G18-03-001-02. AD 259 653. A61-8735.

During this reporting period, several types of regenerated separator materials have become available for test, and some look quite promising at this time. Preliminary tests also indicate that negative plate developments have been made that will more than double the maximum allowable overcharge rate. Cycle life tests are under way, and capacity tests indicate that a longer cycle life will be obtained than in previous tests.

- 1-518. RESEARCH INVESTIGATIONS LEADING TO THE DEVELOPMENT AND EVALUATION OF A CADMIUM-SILVER OXIDE BATTERY HAVING A HERMETICALLY SEALED CONSTRUCTION. J.K. Wilson. Quarterly Progress Report no. 3, 1 Jan. -31 Mar. 1961. Eagle-Picher Co. Joplin, Mo. 15p. illus. Contract: DA-36-039-SC-85370, Proj. no. 3G18-03-001-02. AD 259 653. A61-8735.

During this reporting period, several types of regenerated separator materials have become available for test, and some look quite promising at this time. Preliminary tests also indicate that negative plate developments have been made that will more than double the maximum allowable overcharge rate. Cycle life tests are under way, and capacity tests indicate that a longer cycle life will be obtained than in previous tests.

- 1-519. RESEARCH ON LOW-TEMPERATURE FUEL CELL SYSTEMS. Progress Report no. 10, 15 Feb. -15 Apr. 1960. General Electric Co. Aircraft Accessory Turbine Dept., Lynn, Mass. 21p. illus. Contract: DA-44-009-ENG-3771. AD 243 474. A61-8284.

Redox work conducted under this contract was concluded by issuance of Summary Report no. 9. However, work on the direct, low temperature conversion of fuel gases has been expanded as defined by Exhibit D (Amended). As a preliminary step, the research studies are to be conducted with pure, reactive hydrocarbon fuels leading to knowledge and understanding which will establish whether the (less reactive) heavy hydrocarbon fuels can be utilized in ambient temperature fuel cells. Present work is considered to be of a preliminary nature. During the period covered by the present report, work has been performed on the development of new cell structures for test purposes. In addition, further observations have been made on the behavior of ethylene and ethane in representative ion-membrane cells.

1-520. RESEARCH ON LOW-TEMPERATURE FUEL CELL SYSTEMS.
Progress Report no. 13, 15 Aug. -15 Oct. 1960. General
Electric Co., Aircraft Accessory Turbine Dept., Lynn, Mass.
52p. illus. Contract: DA-44-009-ENG-3771. AD 252 833.
A61-6200.

The objective of this program is to develop a technology which will serve as the basis for design and fabrication of fuel cell packs for ground power units and power for traction devices for military applications. Work has continued on the testing of new cell structures with porous catalyst screen electrodes and porous teflon electrodes. In the former case, some additional catalyst metal powders have been evaluated and performance on ethylene, carbon monoxide and C_4 hydrocarbons and unsaturates has been studied in a preliminary manner. In the case of porous teflon electrodes, several activated carbons have been evaluated. It appears that they may offer the promise of utilizing platinum at much smaller area loadings than has been possible in the past with ion-exchange membrane fuel cells. In addition to hydrogen and oxygen the performance of these electrodes has been evaluated on ethylene and ethane. The areas of some metal catalyst powders have been measured by a standard method. In order to determine the relationship between area and expected cell performance, the polarization curves of a series of known-geometry, platinized screen electrode fuel cells have been obtained. The
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results are inconclusive, but it is felt that further work of this type will shed light on the expected relation between catalyst area and cell performance. Initial results have been obtained by infrared spectroscopy on the surface reaction of ethylene on nickel oxide. Qualitative agreement with somewhat similar work reported in the literature is found. Further application of this technique is expected to shed much light on the nature of fuel reactions on fuel cell anode surfaces. The polarization characteristics of the oxygen electrode in alkaline media as a function of the materials and methods of wet-proofing the platinized carbon electrodes are presented. New carbon materials, with better electrical properties, have been investigated with a view towards improving the polarization characteristics under current drain. The results obtained demonstrate great promise.

- 1-521. RESEARCH ON A 500-WATT SOLAR REGENERATIVE H_2-O_2 FUEL CELL POWER SUPPLY SYSTEM. John M. Lee. Second Semiannual Report, 1 Jan. -30 June 1960. Pratt and Whitney Aircraft Div., United Aircraft Corp., Hartford, Conn., Rept. no. PWA-1846. 108p. illus. Contract: DA-36-039-SC-85259, ARPA order no. 80-59. AD 241 839. A61-4478.

It is the purpose of this contract to conduct research investigations leading to the development of a regenerative 500-watt hydrogen-oxygen fuel cell system. The research investigations during the past six months (January 1 through June 30, 1960) were devoted primarily to establishing the variables for minimum power electrolysis and maximum efficiency gas-liquid separation. Investigations at low temperatures and pressures are nearly complete and have resulted in mathematical correlation of electrolysis data. Efficient gas-liquid separation was demonstrated in the vortex separator test facilities. Preliminary system analysis was started and high-temperature, high-pressure test facilities are being established.

- 1-522. THE SMATKO FUEL CELL AND OTHER SECONDARY FUEL CELLS. Joseph S. Smatko. Presented at the Institute of Radio Engineers Winter Convention on Military Electronics, Los Angeles, California, 1-3 Feb. 1961. 11p. illus. 24 refs. Pam 61-200.

At the present time a variety of regenerative fuel cell systems are being studied and tested. Several employ the hydrogen-oxygen reactant components, with sufficient difference in techniques to justify separate investigation. Since application conditions have enough variables to warrant a number of approaches, fuel cells involving halogens, alkali metals, fused salts, organic compounds, solid metals, and even an unusual substance-ozone, are being studied. Regeneration by various methods are being explored--electrical, thermal, photochemical, and radiochemical. These investigations, as well as others to arise, will eventually yield some interesting and unusual regenerative fuel cells.

1-523. SOLAR REGENERATED FUEL CELL. R. T. Foley. Technical Progress Report no. 14, for August 1960. General Electric Co., Rept. no. GE 2782-TPR-14. 2p. Contract: DA-30-069-ORD-2782. A61-6816.

The objective of this project is to investigate probable fuel cells, fuel regeneration systems, and solar energy collectors for use aboard a space vehicle. The term "fuel cell" is used here in its broader sense meaning a continuous feed cell, or, an enclosed system containing a galvanic cell and the means to regenerate the reactants of this galvanic cell from the products. Phase I of this project established that this regeneration could be achieved either by the sun's thermal energy or its photochemical energy. Up until the February reporting period both approaches had been pursued in a parallel fashion. The emphasis is now on the thermogalvanic approach considering both silver thermocells and iodine thermocells.

1-524. SOLAR REGENERATIVE CHEMICAL SYSTEM. H.P. Silverman Third Semiannual Report, 1 July-30 Dec. 1960. Lockheed Aircraft Corp., Missile Systems Div., Sunnyvale, Calif., Rept. no. LMSD-895034. 59p. illus. Contract: DA-36-039-SC-85245, Proj. no. 3A99-09-001, Task no. 3A99-09-001-04, ARPA order no. 80-59. AD 254 841. 11 refs. A61-7209.

Experimental results of photochemical and thermochemical approaches for converting solar energy to electrical energy are reported. Thermodynamic calculations demonstrating the desirability of the cadmium iodine system as a thermal regenerative system are presented. Initial measurements of the electrochemical parameters including exchange current densities and Tafel slopes as a function of iodine pressure are reported. The first results obtained from the operation of a complete photoregenerative cycle are presented. Data on the stability of the photosensitive chemical system (proflavine- π carbic acid) indicating stability and long cycle life, as well as the effect of such parameters as pH, concentration of components, and time of exposure are also given. The theoretical background of the photoelectrochemical process is discussed with some experimental results on the relationship between photobleaching and photopotential.

1-525. STATUS OF DOFL FUEL CELL PROGRAM ON 1 OCTOBER 1960.
H. F. Gibson. Diamond Ordnance Fuze Labs., Washington,
D. C., Rept. no. TR-891. 24 Oct. 1960. 16p. AD 245 220.
7 refs. A61-2634.

The objective, a brief history, the organization, and status of the DOFL fuel-cell program are given. The program represents the current Ordnance fuel-cell effort. The over-all objective of the program is to develop a technology that will make practicable the use of fuel cells as the prime source of power to propel Ordnance vehicles. The approach to the general problem has been to explore the various concepts to use hydrocarbon fuels, directly or indirectly, in fuel cells. Among many organic and inorganic systems investigated the bromine-bromide couple was the only found to meet most requirements for a redox system and to provide a potential greater than 1.0 volt. A reactants investigation at DOFL has confirmed the choice of the titanous-titanyl couple for the anolyte and the bromine-bromide couple for the catholyte from the standpoint of the electrochemical cell operation. Some of the preliminary results indicate that platinum is a more active catalyst than palladium for the anodic oxidation of methanol, and that sulfuric acid electrolyte gives much less polarization than hydrochloric acid. Formaldehyde appears to be an important intermediate product in this work, and its rate of production is being examined. With 5N sulfuric acid
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electrolyte, complete or nearly complete oxidation of propane and ethylene to carbon dioxide and water was obtained. Several liquid hydrocarbons have shown electrochemical activity at fuel-cell anodes where the hydrocarbon contacted the electrolyte within a diffusion-type electrode of palladium, or platinum-plated porous nickel or platinized carbon. The electrolytes used were 27% potassium hydroxide or 25% potassium carbonate. Hydrocarbon liquids that were reactive in the preliminary experiments are listed in order of decreasing activity: methylcyclohexane, iso-octane, n-heptane, hexene-1, cyclohexene, decalin, cumene, p-xylene, and the nearly inactive toluene.

1-526. STATUS REPORT ON FUEL CELLS, SECOND. B. R. Stein and E. M. Cohn. Office of the Chief of Research and Development, Army Research Office, ARO Rept. no. 2. Dec. 1960. 75p.
AD 253 705. A61-6195.

This report is the second of a series intended to review information of fuel-cell research and development. The contents are essentially limited to material collected since the publication of ARO Report no. 1. This paper includes all information gathered by this office which is not classified or proprietary. Completeness cannot, however, be guaranteed. A source of information that has not been tapped thus far is the patent literature. Arrangements are being made by the Signal Corps to include data from U. S. and foreign patents. Organizations with fuel-cell programs that are not reported here are invited to submit information for inclusion in the next report.

1-527. STUDY OF ION EXCHANGE MEMBRANE FUEL CELL COMPONENTS. R. M. Lurie and R. Schuman. Ionics, Inc., Cambridge, Mass. Interim Report. 30 Dec. 1960. 7p. illus.
Contract: DA-44-009-ENG-4554. AD 252 024. A61-5549.

The objective of this work is to study the hydrogen-oxygen ion exchange membrane fuel cell to determine the factors which limit the performance of the cell and to work in those problem areas, capable of yielding the maximum progress within the time limitations of the contract. Study of the electrodes and membrane assemblies will be included as well as an evaluation of the problem of impurities in the hydrogen and oxygen stream. A bromine-hydrogen fuel cell (Fuelox cell) was constructed and demonstrated. This cell performed in accordance with and exceeded the requirements set forth in the contract. Another bromine-hydrogen fuel cell was constructed, tested, and sent to Ft. Belvoir. Electrode-membrane half cells have been studied with hydrogen and oxygen as well as nitrogen as a control gas. Anion and cation membranes manufactured by Ionics have been utilized in these tests. Membrane formulations are being investigated to obtain low-resistance, and high-water transfer. Methods of obtaining better electrode membrane contact are being studied. Hydrogen-oxygen fuel cells operating as power generators, and hydrogen-hydrogen cells (driven with a battery) have also been tested.

1-528. STUDY OF ION EXCHANGE MEMBRANE FUEL CELL COMPONENTS. R.M. Lurie and R. Schuman. Monthly Report for January 1961. Ionics, Inc., Cambridge, Mass. 7 Feb. 1961. 4p. Contract: DA-44-009-ENG-4554. AD 252 025. A61-5548.

In order to minimize the internal resistance of the fuel cell and optimize cell performance various types of membranes (cation and anion) and catalysts (graphite support placed next to the membrane, embedded in membrane, and catalyst plated on membrane) were tested. The membranes were evaluated in dry cells as well as in half cells. A teflon spraying technique has been used in some experiments to waterproof electrodes. The dry cell has been tested using a 60-cycle alternative current. The results are tabulated (Tables I-IV) and the following effects and conclusions may be noted. 1) The water content of the membrane has no effect on the resistance as measured in a half cell and a small effect as measured in the dry cell. 2) By bubbling the gas going to the test electrode through hot water, moisture may be added to the electrode chamber gradually. Improved performance is especially noted with the dry cell. 3) Waterproofing the electrode allows humidification with less danger of electrode flooding. However, an increased resistance is noted, especially in the dry cell, presumably due to an increased contact resistance. 4) Similar ac and dc resistances indicate that polarization in
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these measurements (hydrogen electrodes) is small. A 60-cycle ac was used. 5) Plating platinum on the membrane gave improved performance on the first attempts. Although embedding the catalyst in the membrane did not show any large improvement in half-cell evaluation, dry cell performance may be better with the embedded catalyst. Plated catalysts gave encouraging results.

- 1-529. SUMMARY OF WORK PERFORMED UNDER CONTRACT TO NOL CORONA FOR YEAR ENDING 30 JUNE 1960.
Charles W. Tobias. California. Univ., Los Angeles. Dept. of Chemistry and Chemical Engineering, Tech. memo 44-9.
21 Nov. 1960. 3p. A61-7066.

This contract calls for the elucidation of the electrode reactions in anhydrous ammonia solutions of several electrode-electrolyte combinations, and for investigations leading to new electrochemical systems for potential use as reserve power supplies. The experimental results are given for the rate of dissolution of calcium metal in ammonium thiocyanate solution at constant temperature (-34°); chemical dissolution of calcium; cell measurements; current efficiency; reference electrodes; development of analytical methods.

- 1-530. TESTING AND EVALUATION OF PRIMARY ALKALINE CELLS AND BATTERIES. Roger Goodman. Semiannual report no. 1, 15 Jan. -1 Sept. 1960. Mallory Battery Co., North Tarrytown, N.Y. 1 Sept. 1960. 35p. illus. Contract: DA-36-039-SC-78320, Proj. no. 3-18-00-700, Task no. 3-18-03-701. AD 257 190. A61-8310.

The testing and evaluation of primary alkaline cells and batteries of the zinc-alkaline-mercury system over a wide range of discharge rate, temperature and storage time are objects of this study. Under the requirements of contract, cells are stored at temperatures of -20° , $+20^{\circ}$, $+70^{\circ}$, $+113^{\circ}$ and $+160^{\circ}$ F. Cyclic storage is between 0° and 130° F. The discharge of cells under load is at the temperatures of -20° , 0° , $+20^{\circ}$, $+40^{\circ}$, $+55^{\circ}$, $+70^{\circ}$, $+120^{\circ}$, $+160^{\circ}$ and $+250^{\circ}$ F. The test discharge of cells includes the range of rates from 1/4 hr to 1000 hrs. The program include the measurement of cells emf and vibration and mechanical shock tests.

1-531. TESTING AND EVALUATION OF PRIMARY ALKALINE CELLS AND BATTERIES. Roger Goodman. Semiannual Report no. 2, 1 Sept. 1960-1 Mar. 1961. Mallory Battery Co., North Tarrytown, N. Y. 82p. illus. Contract: DA-36-039-SC-78320, Proj. no. 3-18-00-700, Task no. 3-18-03-701. AD 257 191. A61-8309.

Progress report on testing and evaluation of primary alkaline cells of the zinc-alkaline-mercury system over a wide range of temperature, discharge rate and storage. The bulk of the report consists of raw data presented in tables and graphs; these consist primarily of discharge rates of batteries stored under varying conditions.

SECTION C. MAGNETOHYDRODYNAMIC DEVICES

1-532. A BRIEF STUDY OF ROCKET-POWERED MAGNETOHYDRODYNAMIC GENERATORS AND ENERGY-STORAGE DEVICES.
J. H. Huth. RAND Corp., Santa Monica, Calif., Rept.
RM-2522-ARPA. 19 May 1960. 45p. illus.
Contract: AF 49(638)-710. AD 251 281. 21 refs. A61-6824.

This Research Memorandum considers the problem of supplying, on short notice, very high levels of electrical power: 1000-100,000 megawatts on the average, possibly delivered discontinuously to the electrical load in micro-second bursts. It would be entirely impractical to use condensers to supply such high average powers, even for a few minutes. One must therefore consider recharging the condensers between bursts from a prime source using chemical or nuclear fuel. The prime converter of the chemical or nuclear fuel must itself be as compact as possible, as well as efficient and quickly startable. For underground installations, it is desirable that the prime power source should also be non-air-breathing. In this report the volumetric performance of large conventional powerplants, gas-turbine units, and fuel-cells is briefly reviewed. Considerable attention is paid to magnetohydrodynamic generators, which, because of their inherent simplicity, are capable of very short start-up times and power-densities that are an order-of-magnitude greater than those obtainable from other devices. Such generators, however, require a highly energetic stream of electrically conducting gas. A

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ground-based chemical rocket exhaust is explored as a source for such a stream. It is concluded that a rocket-powered MHD generator may indeed fulfill the previously stated requirements. However, the following problems remain for further investigation: 1) Finding the best means of producing sufficient ionization in the rocket exhaust for an acceptable electrical conductivity; and 2) developing electrode, insulation, and magnet materials to operate briefly in the 3000°K range.

- 1-533. MAGNETOHYDRODYNAMIC POWER GENERATION USING
NUCLEAR FUEL. Richard J. Rosa. Avco-Everett Research
Lab. Div. of Avco Mfg. Corp. Everett, Mass., Research
rept. 87. Mar. 1960. 18p. illus. AD 234 568. 11 refs.
A61-2142.

This paper starts with a brief review of the basic theory of magnetohydrodynamic (MHD) power generators. The basic electrical properties of gases are reviewed briefly. Over-all performance characteristics of MHD generators are presented as a function of these gas properties. An experimental MHD generator which has been built at the Avco-Everett Research Laboratory is described and its performance discussed. MHD power plant cycles are discussed. A cycle designed for use with a nuclear reactor is described. The reactor in this case would need the same temperature capability as those now being developed for nuclear rocket propulsion. Some of the possibilities for the future are discussed in which more exotic forms of high temperature reactor combined with an MHD generator may make possible nuclear powered systems having, by present standards, very low cost, high efficiency, and/or light weight.

- 1-534. MAGNETOHYDRODYNAMICS AND ENERGY CONVERSION.
Massachusetts Inst. of Tech., Cambridge. Research Lab. of
Electronics. 15 Jan. 1961. p. 73-78, illus. Contract:
AF 33(616)-7624. AD 253 386. A61-7383.

The general purpose of the magnetohydrodynamic research is to explore interaction phenomena in those situations in which the fluid can be considered to be predominantly a continuum. While some of the experimental work is concerned with liquid metals, a large proportion makes use of shock tubes to produce high-velocity plasmas whose interactions with magnetic fields can be studied. One of the research objectives is to extend these techniques to include a greater range of physical parameters. The objectives of the magnetohydrodynamic energy conversion are: 1) To study problems of magnetohydrodynamic flow in order to obtain a better understanding of the many phenomena involved, such as turbulence and wave motion. This involves both theoretical and experimental work. 2) To study systems in which energy conversion can occur between flow energy in a conducting liquid or gas and an electrical system. The systems of interest include steady and nonsteady fluid flow, and dc and ac electrical systems. The work involves theoretical and experimental evaluation of magnetohydrodynamic conversion schemes that have already been proposed and suggestions for new conversion schemes. Present objectives of the thermionic energy conversion lie in four distinct

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areas of direct thermionic energy conversion. The first relates to the theoretical study of the Richardson equation by means of irreversible thermodynamics; the second, to experimental verification of the Saha-Langmuir equation in the region of partial coverage; the third, to the theoretical and experimental analysis of plasmas and sheaths; and the fourth, to the correlation of the effect of emitter work function on the efficiency and ion production rate of cesium converters while operating in the neutralized space-charge region. The objective of the fuel cells study is to learn more about the mechanism of the various chemical, physical, and electrochemical processes that occur simultaneously in a fuel cell. Studies will be directed toward satisfying the criteria of high electrode current density and high efficiency in low-temperature, low-pressure fuel cells that are capable of operating on air and hydrogen and commonly available hydrocarbons.

D. MECHANICAL DEVICES

1-535. RADIATOR-CONDENSER FOR SPACE ENVIRONMENT.
Alan M. Haire. Electro-Optical Systems, Inc., Pasadena, Calif.
EOS Report 310-Final; WADD TR 61-20. 31 Oct. 1960.
Contract: AF 33(616)-6520, Proj. no. 3084, Task no. 30405.
AD 253 791. A61-6806.

A radiator-condenser (R-C) for a Rankine cycle space power system was designed to condense and subcool superheated mercury vapor. Specifications of the R-C are given. The weight of the R-C was to be minimized at design conditions. The design incorporated curved stainless steel tubes welded to tapered stainless steel manifolds and brazed to a steel radiation fin. A test model R-C, designed to reject approximately 1 kw of heat, was tested in a closed-loop laboratory system over a range of vapor inlet temperatures from 810-964°F. Test results are presented in tables. The results demonstrated that a curved tube R-C can be used to condense mercury vapor in a space power system over a relatively wide range of operating conditions. For the range covered in the present investigation, vapor-free liquid flow was obtained at the R-C outlet, and relatively stable conditions occurred in the R-C. Performance of the R-C demonstrated the validity of the design method, except that measured pressure drops were considerably lower than those predicted by currently available analytical methods.

E. NUCLEAR SOURCES OF ENERGY

1. 536. INVESTIGATIONS ON THE DIRECT CONVERSION OF NUCLEAR FISSION ENERGY TO ELECTRICAL ENERGY IN PLASMA DIODE. General Motors Corp. Research Labs. Div., Detroit, Final Report. 31 Dec. 1960. 125p. illus. Contract: NOnr-3109(00). AD 250 673. A61-6822.

The following data are presented: 1) Experimental and theoretical studies on the fission fragment, noble gas plasma diode for direct conversion of nuclear energy to electrical energy; 2) electron emissivity measurements in connection with material research on uranium bearing cathodes; 3) spectral measurements of cesium plasmas yielding data on electron temperatures and ion number densities; and 4) preliminary measurements of a pulsed noble gas plasma diode.

- 1-537. NUCLEAR BATTERY-THERMOCOUPLE TYPE. B. C. Blanke and J. H. Birden. Mound Lab., Miamisburg, Ohio. Monsanto Research Corp., Rept. no. MLM-1106. 1 Oct. 1960. 70p illus. Contract: R-65-8-99811-SC-03-91, Proj. no. 3-99-15-102. AD 251 119. 31 refs. A61-4384.

The potential usefulness of approximately 1300 radioactive isotopes as a heat source for the thermoelectric generator was investigated. Only 47 are found to have the proper characteristics of high specific activity and usable half-life combined with an easily absorbable radiation. These isotopes are discussed showing possible sources of supply, the hazards involved and the expected performance. Three large polonium-210 heat sources were designed and constructed (for battery use), including one for the Snap-3 generator. One small thallium-204 test heat source was made by irradiation. Eight thermoelectric generators were developed and two of these were used as thermoelectric batteries. Theoretical equations for non-semiconductor thermoelectric materials and experimental measurements to verify the Thompson and Peltier effects are given.

SECTION F. SOLAR SOURCES OF ENERGY

- 1-538. COATINGS FOR SOLAR CELLS. Robert M. Witucki and Arthur E. Lewis. Final Report, 15 Jan. 1960-28 Feb. 1961. Hoffman Electronics Corp., Santa Barbara, Calif. Hoffman Science Center. 85p. illus. Contract: NASw-6. AD 258 660. 14 refs. A61-8734.

The theoretical basis for the reflectance of dielectric materials in the ultra-violet and the near infrared was reviewed, as well as the properties required for high emissivity. It was concluded that single thin-film coatings alone, of 1 micron or less in thickness, cannot provide either adequate emissivity or high selective reflectivity of the wavelengths required and still show high transmission from 0.45 to 1.1 micron. A high emissivity was found to be the most important single method of rejecting energy in space. Therefore, attention was directed primarily toward achieving maximum emissivity. Emissivities of the order of 0.9 can only be obtained using coatings of several mils thickness. Silicone coatings were found to be very simple and inexpensive to apply, and within the accuracy of available data to show a predicted performance in space equivalent to the presently used ultraviolet reflecting coated cover glasses. Numerous laboratory tests of limited time duration have shown the selected silicone coating to be stable to the expected environmental conditions during storage as well as in space.

- 1-539. CONTROL APPLICATIONS FOR SILICON SOLAR CELLS. Richard L. Molay. Military Systems Design, vol. 5, no. 3, May-June 1961, p. 16-19.

The purpose of this paper is to suggest new techniques of control design to the person who may be unfamiliar with the solar cell. Some methods of control based on optical principles are described, for example, covering the cell with a polarized filter, placing color filters over the cell, using vernier filters. The open-circuit voltage output of a solar cell is a logarithmic function of illumination intensity within certain limits. This useful characteristic suggests many possible applications. 1) Relays may be operated directly from a photovoltaic readout cell, and 2) a solar cell, a tunnel diode and two uni-tunnel diodes may be combined to accomplish RF switching, etc. The foregoing examples are a sampling of the techniques which have been explored. All derive benefit from the inherent qualities of the silicon solar cell which will never wear out. Since it uses energy from the sun to impart mobility to electrons in its structure, there is no depletion factor. The cell will work under a wide temperature range (-65° and $+75^{\circ}\text{C}$). The cell works better as it gets cooler.

1-540. HIGH-TEMPERATURE, IMPROVED EFFICIENCY, PHOTOVOLTAIC SOLAR ENERGY CONVERTER. J. J. Wysocki, J. J. Loferski, et al. Final Progress Report, 15 July 1958-31 Oct. 1960. Radio Corp. of America. RCA Labs. Div., Princeton, N. J. 31 Nov. 1960. 111p. illus. Contract: DA-36-039-SC-78184. AD 252 010. A61-5454.

This final report summarizes the work of the past two years, and reports the latest work. A theoretical study indicates that GaAs is superior to Si at high temperatures. This conclusion has been experimentally verified at 150°C where a GaAs cell is almost twice as efficient as a Si cell which had the same room temperature efficiency as the GaAs cell. Losses in solar cells due to series resistance and collection efficiency have been examined. Contact resistance is more serious than sheet resistance. For example, in a cell with a 1 cm² area, ten ohms of contact resistance reduces the efficiency by a factor of two while ten ohms of sheet resistance reduces the efficiency by only 15%. The collection efficiency was studied by means of the spectral response with the following conclusions: 1) Measurements of cell efficiency with an incandescent light calibrated by a standard cell are questionable unless the spectral responses of the standard and other cell are identical; 2) a correction of the theoretical conversion efficiency of Si from 22% to 16% is required because of finite diffusion lengths. A study of cascaded and graded (cont.)

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band gap structures indicates that higher conversion efficiencies can be obtained. For example, a cascaded structure consisting of a Ge cell and a CdTe cell yields a conversion efficiency of 19% while the efficiency of either cell alone is 8% for the Ge cell and 15% for the CdTe cell. Another effect which is potentially useful in increasing conversion efficiencies is the long wavelength photovoltaic effect in metal-semiconductor junctions. Such effects have been observed in GaP-Cu and CdSe-Cu junctions. A description of the CdSe material preparation is given along with the long-wavelengths results of CdSe Cu junctions. The PEM effect has been analyzed as a possible means for solar energy conversion but theory and experiment indicate that conversion efficiencies are much less than 1%. A summary of device technology is given. Conversion efficiencies up to 7% have been obtained for GaAs cells with areas on the order of 1 cm². Two new techniques for cell fabrication are described. One is a solution-growth system and the other is an open diffusion system. Diffusion studies show the diffusion constant for P in GaAs is approximately 10⁻¹³ cm²/sec at 7000°C. No GaP has been observed with x-rays but a surface phase other than GaAs appears to be present. The rate of decrease in conversion efficiency of n on p Si solar cells bombarded by 8.3 mev protons is less than that of p on n cells. Quantitative comparisons

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are difficult, because of differences in initial efficiency and other factors. Spectral analyses indicate that most of the damage is in the base. Some damage studies have been made in GaAs.

1-541. INVESTIGATION OF COMPOSITE OR STACKED VARIABLE ENERGY GAP PHOTOVOLTAIC SOLAR ENERGY CONVERTER. James W. Burns. 1 Sept. 1959-31 Aug. 1960. Electro-Optical Systems, Inc., Pasadena, Calif., Rept. no. EOS 400-Final. 86p. illus. Contract: DA-36-039-SC-85244. AD 253 484 169 refs. A61-6811.

A theoretical analysis is given of the performance of composite photovoltaic solar energy converters consisting of two separate p-n junction cells of differing energy gaps. The analysis considers the spectral efficiencies of the separate cells and the effects of saturation currents as a function of energy gaps. The failure of the forward current to vary as rapidly as $\exp(qV/kT)$ is discussed on the basis of non-radiative recombinations in the space charge layer. The effect of such recombinations on cell efficiency is analyzed, and graphs of efficiency vs energy gaps in the composite cell are given for the ideal case of no non-radiative recombinations and for several recombination rates. For the ideal case the optimum energy gaps are found to be 1.1 ev and 1.65 ev, and the maximum efficiency 32.5%. The optimum energy gaps increase with a departure from the ideal, and the maximum efficiency decreases. A correlation is drawn between the efficiency of carrier collection and the effect of diffused layer resistance, and it is found that the optimum junction depth in a solar cell is approximately one-fourth of the minority

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carrier diffusion length. On the basis of the analysis, Si is chosen for the lower-energy-gap component of the composite cell, and AlSb and CdSe are selected as possible materials for the higher-energy-gap component. The purification of Al and the growth of crystals of AlSb are described in detail. A description is also given of the preparation of crystals of CdSe, but neither AlSb nor CdSe were prepared with sufficient purity to warrant solar cell fabrication. The results of measurements in sunlight of the power output of a composite cell in which Si and CdS form the active elements are given. As expected, these results indicate that CdS is not one of the optimum materials for a composite solar cell.

1-542. INVESTIGATION OF COMPOSITE OR STACKED VARIABLE ENERGY GAP PHOTOVOLTAIC SOLAR ENERGY CONVERTER. J. W. Burns and W. Evans. Second Semiannual Progress Report, 1 Jan. -1 July 1960. Electro-Optical Systems, Inc., Pasadena, Calif. 32p. illus. Contract: DA-36-039-SC-85244. AD 242 547. 9 refs. A61-4140.

The work herein reported is directed toward the attainment of improved photovoltaic solar cell conversion efficiencies by means of the stacked or composite energy gap solar cell structure. The optimum values for the energy gaps of the semiconductors in a composite cell have previously been determined to be 1.1 ev and 1.65 ev. A discussion is given of the semiconducting materials having energy gaps approximating these values. On the basis of this discussion, Si is chosen for the component of lower energy gap and AlSb and CdSe are selected as possible materials for the higher energy gap component. The purification of aluminum and the growth of single crystals of aluminum antimonide are described in detail. It is found necessary to purify the aluminum by a vacuum heat-treatment at 1000°C in the crystal furnace chamber just prior to forming the compound, and the difficulty in initiating single crystal growth of AlSb centers around this purification process, during which it is necessary to maintain the surface cleanliness of

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the seed. A description is given of the construction of a furnace for the deposition of single crystals of CdSe from the vapor phase. This material does not appear as promising for solar cells as does AlSb, however. The results of measurements in sunlight of the power output of a composite solar cell in which Si and CdS form the active elements are given. As expected, the results indicate that CdS is not one of the optimum materials for a composite solar cell. An experimental program is being conducted to prepare suitably doped single crystals of AlSb, to be utilized in the high energy gap component of the composite solar cell.

1-543. INVESTIGATION OF HIGH-TEMPERATURE, IMPROVED EFFICIENCY PHOTOVOLTAIC SOLAR ENERGY CONVERTER. J. J. Wysocki, J. J. Loferski, et al. Sixth Triannual Progress Report, 16 Mar. -15 July 1960. David Sarnoff Research Center, Princeton, N. J. 31 July 1960. 29p. illus. Contract: DA-36-039-SC-78184. AD 241 690. A61-8317.

GaAs cells made by diffusing Zn in the open furnace are equivalent to those made in a sealed ampule except that the surface concentration is about an order of magnitude lower. Cells with efficiencies as high as 5.2% have been made in this furnace. The furnace will be used to investigate other impurities and gaseous ambients. The absolute spectral response of two GaAs cells indicate a lifetime in the diffused region of approximately 10^{-10} sec. The data is being used to determine the high-energy absorption constant of GaAs. Absolute spectral responses of a series of Si cells with p- and n-type surface layers are being used to determine the lifetime in the base and in the diffused skin. The base lifetime agrees with that measured by other means for the shallower junctions under 5μ . The agreement is poorer for larger junction depths. The data will be analyzed to determine the surface recombination velocity and absorption constant. Conversion efficiency measurements using a tungsten light source calibrated with a standard cell agree with sunlight measurements only when the spectral response of the cell

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to be measured is similar to that of the standard. A minimum requirement is that the cell and standard be made of the same semiconductor. Photovoltaic effects have been seen in metal-semiconductor junctions comprising Cu or Au and CdSe. Quantitative measurements on these junctions including quantum yield and spectral response are in progress. The threshold for radiation damage produced by electrons in phosphorous-diffused Si appears to be 225 kev. This threshold is significantly higher than the 165 kev measured for born-diffused Si. The reason for this difference in thresholds is not yet known.

1-544. INVESTIGATION OF LARGE-AREA SOLAR CELLS UTILIZING SPHERES OF SILICON. Final Technical Report, 1 Oct. 1959-30 Sept. 1960. Hoffman Electronics Corp., El Monte, Calif., Semiconductor Div. 93p. illus. Contract: DA-36-039-SC-85243, ARPA no. 80-59. AD 246 873. A61-2846.

Theoretical analysis and experimental tests show, that the fabrication of large-area photovoltaic solar energy converters is possible by using a composite of a multitude of intimate individual cells prepared from spheres of silicon. Optical-geometrical factors were considered and theoretical analysis shows that about 97% of the incoming light can be intercepted by the spheres in the composite cell, without the use of a lens system. The effect of a lens system and the dependence of the amount of light utilized by the cell was also investigated. Semiconductor-electrical factors were investigated and the limitation of cell size, due to the metal contact resistance, was determined. The p-layer resistance of a 3-mm-diameter sphere was found to be much lower than the p-layer resistance of a 1 x 2 cm flat-type cell. Efficiencies of sample cells were usually between 4 and 9% based on total device area; however, efficiencies as high as 10.8% were obtained.

- 1-545. INVESTIGATION OF NEW SOLAR REGENERATIVE FUEL CELL SYSTEMS. Second Semiannual Technical Summary Report, 1 Jan. - 30 June 1960. Frank A. Ludwig. Electro-Optical Systems, Inc., Pasadena, Calif., EOS Rept. 420-2Q-2. 10 July 1960. 161p. illus. Contract: DA-36-039-SC-85270, Proj. no. 3A99-09-001, Task no. 3A99-09-001-04. AD 255 462. A61-7413.

The theoretical efficiency of a thermally regenerative fuel cell was determined by setting up 12 models. Kinetic analyses performed on systems which looked promising from a thermodynamic point of view eliminated all but a few. Experimental data on the H_2SO_4 vaporization-condensation fuel cell indicates good closed-cycle operation at current densities of 20 ma/cm² at 0.3 volt. It has run for 18 hours at a time without any loss in performance or attack of container materials or electrodes. It requires no pumps and should operate well in a zero-gravity environment. The ultimate efficiency is the Carnot efficiency. The main problem remaining is to eliminate thermal conduction losses.

- 1-546. INVESTIGATION OF SINGLE ENERGY GAP SOLAR CELL MATERIAL. Robert J. Robinson. Final Report, 1 Sept. 1959-31 Aug. 1960. Illinois Inst. of Tech., Chicago. Armour Research Foundation, ARF 1155-15, Final Report. 48p. illus. Contract: DA-36-039-SC-85247. AD 247 267. A61-7385.

This is the final report of a one-year program to develop, if possible, a single-gap solar cell material which lends the possibility of lower production cost, increased practical efficiency, and better high-temperature characteristics than can be expected from silicon. Cadmium telluride (CdTe), the material chosen for the study, is a comparatively new material in semiconductor technology, and the principal emphasis during this program has been on obtaining semiconductor useful single crystals from the melt. Equipment was set up and utilized to grow CdTe by two different methods. The first, and simpler method is a technique in which polycrystalline CdTe is sealed off in a quartz tube and passed through a gradient (or Stockbarger) furnace. The first ampoules were characterized by a high degree of distortion crystallization. Progress was made in growing dense, nearly single crystal ampoules with resistivities between 10^{-1} to 10^6 ohm cm depending upon indium dopant concentration. Better minority carrier lifetimes and greater uniformity from a semiconductor viewpoint are needed before the material is

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usable for fabricating solar cells. The limitations of the Stockbarger techniques became evident early in the program and a different, more elaborate method was indicated. Concurrent with the Stockbarger studies a controlled-atmosphere, zone-refining apparatus was set up and calibrated. Only recently have ampoules become available from this method. Solar cell fabrication studies on the currently available material (Stockbarger technique) were made in order to determine how cadmium telluride behaves during the fabrication cycle. The lack of wide area photovoltaic response after fabrication, even though previous probe studies had indicated a photovoltage, and the tendency to pit during heat treatment indicated inhomogeneous material. Thermoelectric probe measurements showed that the material was inhomogeneous with interspersed n- and p-type regions.

1-547. INVESTIGATION OF SINGLE ENERGY GAP SOLAR CELL MATERIAL. Robert J. Robinson. Technical Summary Report no. 1, 1 July-31 Dec. 1960. Illinois Inst. of Tech., Chicago. Armour Research Foundation, Rept. no. ARF 1175-3. 26p. Contract: DA-36-039-SC-87381, ARPA order no. 80-61. AD 251 950. A61-8285.

The first year's program on the Investigation of Single Energy Gap Solar Cell Material with its emphasis on crystal growth studies has been briefly reviewed, the lack of homogeneity in the cadmium telluride boules obtained from Bridgman technique is contrasted with the cadmium telluride obtained from the controlled-atmosphere zone-refining furnace. The fact that the material first became available from this furnace during the last two months of the first year's contract is the reason that the technique is discussed in the report. Further, this gives a continuity to the periodic reports. Preliminary optical absorption measurements have been made and the shape of the absorption edge in cadmium telluride is contrasted with that of silicon, because of its implications for fabrication of p-n junctions. Implications of the more rapidly rising edge in cadmium telluride are briefly discussed. Defect bands at photon energies in the 0.5 ev region are noted and also the

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fact that concentration varies from sample to sample. The defect centers are consistent in energy with the centers noted using current fluctuations in photoconducting cadmium telluride. This technique was discussed in the first periodic report. From the fluctuation studies it is suggested that the centers are approximately 0.5 ev below the conduction band. A portable system has been designed and built for alloying and diffusing in vacuum, inert atmosphere, or diffusant under static or flow conditions which allows for possible transport from one laboratory to another while the sample remains in its original atmosphere and with the further possibility of partial in situ experiments. Photovoltaic cells have been fabricated, using a low temperature (400°C) technique on which to put a p-type film. Photovoltages greater than 200 millivolts have been measured.

1-548. IRRADIATION OF BARE SILICON SOLAR CELLS. T. H. Clarke and D. H. Tompkins. Presented at the American Institute of Electrical Engineers Winter General Meeting, New York, 29 Jan. - 3 Feb. 1961. 3p. illus. Paper No. CP 61-283.

The General Electric Company has conducted experimental investigation of the effect of electron bombardment on 8% silicon solar cells at various energy ranging from 1.2 mev to 2.0 mev. A 2-mev Van De Graaf machine at High Voltage Engineering Corporation, Burlington, Massachusetts, was used. The following conditions were used: electron energy in mev: 1.2, 1.4, 1.6, 1.8, 2.0; dosage in electrons/cm²: 1×10^{15} , 3×10^{15} , 6×10^{15} , 10×10^{15} . This paper describes the testing apparatus used and an analysis of the results with the curves obtained from the data taken. Calculations using range energy curves predicts that 1.7 mev electron striking cells after passing through 50 mils of glass should be equivalent to 1.2 mev electrons incident on bare cells. Curves in Figure VIII and Figure III support this.

1-549. MATERIALS FOR SOLAR-ENERGY SYSTEMS. Roger E. Gaumer.
Space/Aeronautics, vol. 36, no. 4, Oct. 1961, p. 60-5.

The basic thermophysical parameters that determine a material's usefulness for solar-energy systems and for the external heat protection of spacecraft are solar absorptance, infrared emittance, and reflectance. This survey shows how these parameters are determined, how they apply to the different elements of power-conversion and temperature-control systems, and compares available materials on this basis. Methods of determining the thermophysical parameters and environmental and structural factors are also discussed.

1-550. PHOTOVOLTAIC CADMIUM SULFIDE. Fred A. Shirland.
Harshaw Chemical Co., Cleveland, Rept. no. ARL 60-293.
Aug. 1960. 71p. illus. Contract: AF 33(616)-3466, Proj.
no. 7116, Task no. 70715. AD 246 547. 7 refs. A61-7656.

Empirical procedures have been developed enabling CdS photovoltaic cells and batteries of approximately 5% efficiency to be fabricated. The cells are made from commercial CdS, which is doped with 0.003 wt% of InCl_3 and sintered. Polycrystalline ingots are grown from the vapor phase at 1260°C . Rhodium collector electrodes are formed by electrodepositing finely divided copper on the back, oxidizing it and heat treating. The barrier surface is then contacted with silver paint. Performance and spectral response on these cells is different from that of other known photovoltaic cells. Lacking a fundamental understanding of the barrier in the CdS cell, it is possible to predict the upper limit of conversion efficiency possible under solar or other illumination. It is recommended that the research effort on CdS solar cells be focussed on fundamental investigations.

- 1-551. PHOTOVOLTAIC CELLS. PART II. AN ANNOTATED BIBLIOGRAPHY. Maureen A. Pearcy. Lockheed Aircraft Corp. Missile Systems Div., Sunnyvale, Calif., Special Bibliography, SB-60-28. Dec. 1960. 39p. AD 251 572. A61-7386.

The first volume of this bibliography, issued in August 1960, presented a general survey of the literature on photovoltaic cells from 1910 to 1960. This supplement is a more inclusive treatment of the literature of 1959 and 1960, and contains reports and articles which have issued since August 1960.

- 1-552. PHOTOVOLTAIC CONVERSION. COMPARISON OF P-N AND N-P SILICON SOLAR CELLS. Joseph Mandelkorn, James Kesperis, et al. Army Signal Research and Development Labs., Fort Monmouth, N. J. 14th Annual Power Sources Conference, 17-19 May 1960. 3p. QC 603.U58

Preliminary results are presented for the phosphorous-diffused silicon solar cells. The investigation at its present phase has shown that it is possible to obtain high-efficiency phosphorus-diffused cells. Efficiencies of 11-12% have been obtained using krylon coatings, and it is estimated that the use of silicon monoxide as an antireflective coating would have increased these efficiencies to the 12-13% range. Low contact resistances and consistently low values of reverse leakage current have been obtained. Several of the cells had low junction impedances, i. e., n values below 2. The performance characteristics of the cells made showed no significant difference from those of boron-diffused cells except in radiation resistance. Recent information indicates that the perfection of grown silicon crystals is influenced by the impurity element used as a dopant and by the concentration of the impurity element in the crystal. Highly doped boron crystals can be more readily grown with considerably greater perfection than highly doped n material. Since boron doped crystals of approximately 0.5 to 1 ohm-cm resistivity

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would be used to make phosphorus-diffused cells, this should prove advantageous. Furthermore, evidence is accumulating that the diffusion of high concentrations of boron into silicon is accompanied by extensive damage to the material structure and properties. The situation concerning phosphorus diffusion at high concentration is now under investigation.

1-553. PHOTOVOLTAIC CONVERSION. LARGE AREA SILICON SOLAR CELLS. M. B. Prince. Army Signal Research and Development Labs., Fort Monmouth, N. J. 14th Annual Power Sources Conference, 17-19 May 1960. p. 26-27.
QC 603.U58.

"Large-area silicon cells" means devices having an area greater than 1 in². Solar cells utilizing spheres of silicon are being developed at Hoffman Electronics Corporation, Semiconductor Division. The construction of these cells is given in Figure 1 of this paper. The large-area device is a composition of a multitude of minute silicon photovoltaic cells. The individual cell is a spheric n-type silicon semiconductor body the surface of which has been diffused with boron to form p-type material. A number of diffused spheres are set onto a plastic sheet partially immersed in semi-polymerized plastic which is then cured, and a metallic film, consisting of four layers (electroless gold, silver, copper and electrolytic gold), is deposited over the spheres and the plastic. Further processing steps include application of another plastic film, lapping (to expose the spheres), etching, applying more plastic material, deposition of another metallic film, and insulating. The electrodes are films of metal which bridge the space between spheres and physically connect the cells in a parallel arrangement. Present investigations in the development of this type of large-area silicon solar cells include the

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following: 1) A study of the optimum sphere arrangement, 2) optimum sphere size and spacing, 3) reflection properties of the meniscus, 4) depth of the p-n junction, 5) p-layer resistivity, and 6) other semiconductor-electrical factors. Large single-crystal silicon solar cells require techniques which include the growing of large single crystals of silicon, cutting of slices from these crystals and diffusion and fabrication of the solar cell. At the present time cells can be made in areas up to 1 x 3 in. with efficiencies greater than 12%. The following techniques applicable to the development of large-area solar cells are under investigation at Hoffman and several other laboratories: 1) Evaporation of silicon onto silicon and other substrates, 2) vapor deposition of silicon onto silicon and other substrates, 3) casting silicon into thin sheets and other special forms, 4) sintering of silicon into special forms, and 5) use of silicon chips and powder.

1-554. RESEARCH DIRECTED TOWARD THE IMPROVEMENT OF THE EFFICIENCY OF SILICON BATTERIES BY UTILIZATION OF UNABSORBED PHOTONS. Technical Operations, Inc., Burlington, Mass., Rept. no. TO-B61-24; AFCRL-475.
1 May 1961. 11p. illus. Contract: AF 19(604)-7306.
AD 257 495. A61-8320.

The objective of the silicon solar battery research program was to investigate the possibility of increasing the power output of silicon solar cells by sensitizing the cells to those spectral regions (ultraviolet and infrared) in which they do not respond, and by increasing the absorption and efficiency of the cells in the spectral region in which they do respond. The conclusions of the investigation are: 1) The industry has now optimized an absorption and response of silicon solar cells in the region of spectral response (0.45-1.0 A), 2) sensitization of the cells in the ultraviolet spectral region by phosphors is feasible, but the intensity of fluorescence required to drive the cell appears to be greater than that easily achievable by surface coating. Sensitization by chemical sensitizers in this spectral region does not appear to be possible. 3) Sensitization of the solar cells in the infrared region by dye sensitization does not appear to be possible.

1-555. SEMICONDUCTOR PHOTOVOLTAIC CONVERSION.
J. J. Wysocki, B. Goldstein, et al. First Triannual Report,
1 Nov. 1960-28 Feb. 1961. Radio Corp. of America. RCA
Labs. Div., Princeton, N. J. 31 Mar. 1961. 41p. illus.
Contract: DA-36-039-SC-87417, Proj. no. 3A99-21-001.
AD 258 131. A61-8298.

The solution-growth technique for fabricating GaAs solar cells and its limitations are discussed. The best cell made by this method had an efficiency of 2%. Preliminary work on hetero junctions and cells made from GaAs alloys is reported. The diffusion of P in GaAs is slowed down by the presence of Zn (5×10^{19} atoms/cc) by a factor of 2 at 1120° . No GaP is observed even for P-surface concentrations of $10^{22}/\text{cm}^3$. Johnson's data for the solar irradiance has been converted to yield the number of available photons outside the earth's atmosphere. The total number of photons is $6.4 \times 10^{17}/\text{cm}^2/\text{sec}$, and their average energy is 1.36 ev. The critical flux required to reduce the efficiency of GaAs solar cells by 25% was $1.8-3.5 \times 10^{15}$ electrons/ cm^2 at bombardment energies of 800 kev. The fabrication of oxygen-free Si n on p cells is discussed. Critical fluxes for three such cells varied from 1.5×10^{15} to 2×10^{16} electrons/ cm^2 at 800 kev. Absolute spectral responses of these cells indicate damage in the base and possibly to the diffused skin. The study of bulk conductivity changes as a result of
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electron bombardment indicate some change in an n-type Si blank with $2.7\Omega\text{-cm}$ resistivity for electron energies as low as 185 kev.

- 1-556. SILICON PHOTOVOLTAIC CELLS AND THE UTILIZATION OF SOLAR ENERGY. C. A. Escoffery and Werner Luft.
International Rectifier Corp., El Segundo, Calif. June 1960.
14p. illus. 24 refs. A61-7037.

Silicon photovoltaic cells are being widely used in numerous applications, both celestial and terrestrial, for the direct conversion of solar radiation into electric power. The possibility of relieving the world energy problem by the photovoltaic process is discussed. Present day silicon solar cells have conversion efficiencies of 12% or more, and the preparation, operating principles, and characteristics of silicon solar cells are presented. The control of cell temperature in space vehicles is discussed in terms of the absorptance and emittance of radiation by the silicon cell surface, and measured values of these parameters are shown for uncovered cells and for cells provided with glass or with silicon oxide films.

- 1-557. TESTS OF A SOLAR-POWERED AID TO NAVIGATION. Office of Engineering, Coast Guard Headquarters, Washington, D. C.
Testing and Development Div. 14 June 1961. 5p. illus.
Proj. J24-2/1-1-11. A61-8664.

This report describes the operational tests of a solar-powered battery charger for a U. S. Coast Guard aid to navigation. The system tested consisted of four watertight modules of 80 Type 2-A Hoffman Cells designed for 6-volt application. The four modules were connected in a series-parallel array to sustain a 12-volt 1.35-amp lamp load flashing on a one-tenth duty cycle. The tests demonstrated the ability of the system to carry typical aids to navigation loads through two successive winters at the Los Angeles, California, test site.

SECTION G. THERMIONIC DEVICES

- 1-558, A CESIUM VAPOR THERMIONIC CONVERTER USING A THORIUM DISPENSER CATHODE. J. M. Houston. General Electric Co. Research Lab., Schenectady, N. Y., Rept. AFCRL 253, Scientific Report no. 1. May 1960. 5p. illus. Contract: AF 19(604)-5472. A61-7369.

A thermionic heat-to-electricity converter was tested which consisted of 13.3 cm^2 thorium dispenser cathode spaced 1 mm from a copper or fernico anode. Current-voltage characteristics and power output were taken as a function of cathode temperature and cesium pressure. At a cathode temperature of approximately 2200°K , an anode temperature of 450°K , and a cesium pressure of $2 \times 10^{-2} \text{ mm}$, a dc power output of 42 watts (30 amp at 1.41 volts) was delivered to a resistive load at an over-all efficiency of 7%. The effect of anode temperature on converter power output was explored by recording a series of current-voltage plots at different anode temperatures. The power output went through a maximum at an optimum anode temperature where the anode work function was minimum (optimum Cs coverage). The changes in anode work-function were also observed by measuring the thermionic emission from the anode. The effect of an applied axial magnetic field on the converter output was explored. At low Cs pressures a field of 20 gauss reduced power output to $2/3$ of its zero-field value. At high Cs pressures a magnetic field of 80 gauss had no measurable effect on converter output.

- 1-559, DESIGN STUDY FOR ADVANCED SOLAR THERMIONIC POWER SYSTEMS. ITEM II-PART II. CLOSE-SPACED VACUUM THERMIONIC GENERATOR. Thompson Ramo Wooldridge Inc., Cleveland, Rept. no. 4166, and Thermo Electron Engineering Corp., WADD TR-60-698, pt. 2. Sept. 1960. 91p. illus. Contract: AF 33(616)-7411, Proj. no. 0(3-3145), Task no. 60962. A61-7036, pt. 2.

In this report, general descriptions of the design of the unit and the assembly procedures are given and an analysis of the operating characteristics of the converter is presented. Based on Langmuir's space-charge solution, the power output and ideal efficiency of the unit are first evaluated. It is found that 98 cells, each with an emitting area of 6.45 cm^2 , operating at a temperature of 1500°K will give a total power output of 290 watts. By connecting half the cells in series, an output voltage of 27.5 volts is obtained. The ideal efficiency is found to be 8%. Subsequently, the additional heat losses due to conduction through and radiation by the structure of the unit are evaluated, and the over-all efficiency is found to be 6.4%. From the power output and the efficiency, the necessary radiator surface at 900°K is estimated, and it is proved necessary to extend the surface of the trays by fins to obtain sufficient area to reject the heat at 900°K . Finally, the

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temperature drop along the cell and the fins is evaluated and is shown to be within acceptable limits. The design of the electrical heat source is given and is illustrated. In this design, a tantalum cylinder is heated by electron bombardment to 2000°K and then the cells are heated by re-radiation from the cylinder. In the same section, an evaluation of the necessary window dimensions for solar heating is presented. The following items pertaining to a design study of the close-spaced vacuum thermionic converter are also discussed: a preliminary design of the voltage regulator, a description of experimental test procedures, some experimental results which substantiate the design of the vacuum unit, and the design specifications of the various parts of the unit.

1-560. DESIGN STUDY FOR ADVANCED SOLAR THERMIONIC POWER SYSTEMS. ITEM III. ELECTRICAL CHARACTERISTICS STUDY. Thompson Ramo Wooldridge Inc., Rept. no. 4262. and Thermo Electron Engineering Corp., WADD TR 60-872. Dec. 1960. 83p. illus. Contract: AF 33(616)-7411, Proj. no. 0(3-3145), Task No. 60962. A61-7035.

Results of a theoretical and experimental study of electrical characteristics of cesium-vapor and vacuum thermionic generators are presented. This study was conducted to support and supplement designs for 250-watt generators using cesium and vacuum converters presented in the Interim Summary Technical Report (WADD TR-60-698). Also, information on response of thermionic generators to sudden changes in load was sought to support recommendations for conversion and regulation of the converters' output. Such recommendations are given. The results of this study indicate that a non-optimized cesium converter, operating at emitter temperatures below that assumed in the Interim Summary Technical Report (WADD TR-60-698) can give the performance predicted in that report. Indications are that further testing will disclose conditions for substantially improved performance. A wire spacer technique for vacuum diodes has been investigated and proven entirely successful. This technique offers substantial advantages

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over sapphire spacers and simplifies considerably the design for the 250-watt vacuum generator. The response of both cesium and vacuum generators to sudden changes in load appears to be instantaneous for all practical purposes, thereby permitting the use of switching-type voltage regulators which offer particular advantages in space applications.

1-561. POTENTIAL DISTRIBUTIONS IN A LOW-PRESSURE
THERMIONIC CONVERTER. P. L. Auer. General Electric Co.
Research Lab., Schenectady, N. Y., Rept. AFCRL 282,
Scientific Rept. no. 4. July 1960. 25p. illus. Contract:
AF 19(604)-5472. A61-7372.

A planar diode model of a low-pressure cesium-filled thermionic converter is treated. It is assumed that all ions and electrons are created at the surface of the hot cathode with a Maxwellian distribution corresponding to the cathode temperature. The charge species are then assumed to move through the plasma consisting of electrons, ions, and neutral cesium atoms as free particles under the influence of their mutual space charge field. A method is outlined by which the potential distributions corresponding to different operating conditions may be calculated completely. In this fashion the operating characteristics of the converter may be related to the self-consistent space charge potentials. Instabilities as possible sources of tube oscillations are briefly discussed.

- 1-562. RESEARCH ON CESIUM-VAPOR CELLS EMPLOYING CARBIDE CATHODES. R. W. Pidd and H. L. Garvin. Yearly Technical Summary Report, 1 May 1960-31 Jan. 1961. General Atomic Div., General Dynamics Corp., San Diego, Calif., Rept. no. GA-1973. 7 Feb. 1961. 43p. illus. Contract: NONr-3193(00). AD 256 485. 11 refs. A61-6821.

Vacuum emission studies were made on cathode materials containing ZrC and UC of various proportions. A cathode of $\text{ZrC}_{0.80}$ - $\text{UC}_{0.20}$ solid solution was installed in a cesium thermionic diode and studies were made of the electrical output characteristics, ion generation mechanism, and effective electron temperatures at various cesium pressures.

- 1-563. TESTS OF A CESIUM THERMIONIC CONVERTER DESIGNED TO UTILIZE SOLAR ENERGY IN OUTER SPACE. V. C. Wilson and Jackson Lawrence. General Electric Co. Research Lab., Schenectady, N. Y., Rept. AFCRL 281, Scientific Rept. no. 3. Aug. 1960. 11p. Contract: AF 19(604)-5472. A61-7371.

A cesium thermionic converter with an integral radiator for solar application has been designed and tested. Design, construction, and processing techniques are discussed. Performance data under various operating conditions are given including a maximum output power at 1800°C of 85 watts with 15% efficiency. The electric generator and reject heat radiator weighs 7.5 lb/kw of output electricity.

1-564. VACUUM THERMIONIC ENERGY CONVERTER. J. E. Beggs.
General Electric Co. Research Lab., Schenectady, N. Y.,
Scientific Rept. no. 2. July 1960. 9p. Contract:
AF 19(604)-5472. A61-7370.

While it has been demonstrated that a practical thermionic converter can be built using existing vacuum tube materials and techniques, additional research and development work is needed to realize or approach the high outputs and efficiencies that are theoretically possible. Research studies in the basic physics of thermionic work function could produce materials that might increase considerably the useful output voltage and current. For use at the elevated temperatures indicated for a vacuum converter having high output and efficiency, additional work is needed to find materials that have low gas evolution, high strength and resistance to oxidation.

SECTION H. THERMOELECTRIC MATERIALS

1-565. DEVELOPMENT OF A SEMICONDUCTOR FILM-TYPE THERMOCOUPLE ENERGY CONVERTER. Quarterly Technical Report no. 5, 1 Oct. 1960-1 Jan. 1961. Minneapolis-Honeywell Regulator Co., Research Center. Hopkins, Minnesota. 17p. Contract: DA-11-022-21X4992.501-ORD-3230. AD 251 010. A61-6209.

The major effort during this period has been concentrated on the fabrication of the sprayed nickel oxide film generator, described in the last report. Changes in design and fabrication techniques have been made as required by certain difficulties encountered in this construction. One of the initial problems was in the design of the ceramic substrate. The base material on to which both the platinum and doped nickel oxide layers was applied was an alumina ceramic. These alumina plates were machined from sintered stock and fired to 1400°C. The platinum coating has been formed by application of Hanovia's no. 69 26 paste, fired on at 1400°C. It was found that a single coating, although apparently quite good, was electrically discontinuous when notched into 0.025-in. strips.

1-566. LOW TEMPERATURE BA-2270/U-XLT-1 BATTERIES. J. W. Paulson. Interim Report no. 2, 15 Aug. 1960-15 Feb. 1961. Ray-O-Vac Co., Div. of The Electric Storage Battery Co., Madison, Wisconsin. 28 Feb. 1961. 11p. Contract: DA-36-039-SC-78144, Task no. 3G18-03-001-01. A61-8374.

This is an interim progress report on the production of 500 low-temperature BA-2270/U-XLT-1 batteries of the flat-cell type for initial and delayed service testing. The testing was to be conducted by the contractor and the Signal Corps. The report outlines the progress of construction during the period. Both lithium chloride and lithium bromide electrolytes were tested. Tests were run on batteries which had been stored for six months. Performance was generally lower because of electrolyte leakage due to defects in construction. In those batteries which were not faulty, loss was on the order of 10-20%.

1-567. OPTIMIZATION OF THERMOELECTRIC ENERGY CONVERTERS.
Bimonthly Progress Report no. 3, 15 Aug. -14 Oct. 1960.
General Electric Co., Aircraft Accessory Turbine Dept., Lynn,
Mass. 60p. Contract: NObs 78403. AD 258 730. 11 refs.
A61-8736.

A detailed analysis of the first thermal system to be studied has been completed. The system consists of saturated steam at 533°K (500°F) as the heat source, a thermoelectric converter of conventional configuration, and sea water at 291°K (65°F) as the heat sink. The thermoelectric materials considered have the properties of the best currently available. The analysis, completed with the aid of a computer program designated NOBS-2, includes the effects of the electrical conductors contact resistances, and materials used for the container. Electrical losses in the contacts and conductors are considered as a part of the electrical load, in the NOBS-2 analysis. In another analysis, NOBS-3, for which the derivation of the equations is presented in this report, the losses in the contacts and conductors are considered as being internal to the generator. Graphical results are shown, indicating the power per unit weight, volume, and area that can be expected for a range of efficiencies. A forsterite encapsulating cell, to which iron end-caps were affixed by means of an iron-rich alloy of iron and titanium, has successfully been operated at temperatures in excess of 1400°C . This temperature is
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considered to be the limit of operation for cells containing forsterite ceramic bodies. Inclusion of sodium carbonate and an excess of tellurium in p-type lead telluride prior to its encapsulation has been found to prevent the conversion of the material to n-type lead telluride during the process. Erratic values have been found for the contact resistance, however, and further development is required before the procedure is deemed reproducible. A method for encapsulating chromium antimonide, which expands on solidification, in standard iron-titanium-forsterite cells, has been perfected. A small, crushable quartz tube is inserted in the powdered CrSb prior to its fusion, and its pulverization by the solidifying thermoelectric material is sufficient to relieve the stresses on the forsterite tube. Problems in the mixing of magnesium and antimony during the synthesis of Mg_3Sb_2 have been overcome, as have those of its volatilization during the process. Crude electrical measurements indicate that the substance has a high resistivity, by the standards used in thermoelectricity. Magnesium has been found to be useful for producing a bond exhibiting negligible contact resistance between magnesium antimonide and iron. Zone-refining of lithium has been accomplished, using a turntable-shaped apparatus for the purpose. From infrared reflectance measurements on new specimens of CrSb, the substance appears to possess a band-gap energy of about 0.8 eV. The band-gap data based on electrical measurements
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differ greatly from this value. The presence of large concentrations of extrinsic carriers may be responsible for the apparent discrepancy.

Hall-effect measurements indicate that CrSb has carriers of extremely low mobility, as is also suggested by Seebeck-coefficient data. Calcium silicide, calcium stannide, and calcium plumbide have been prepared in tantalum-lined iron pipes with steel end-caps. Despite evidence of leakage of calcium during the synthesis, x-ray analysis indicated complete absence of starting materials from the resulting ingots. Welded capsules, made entirely of tantalum, have been perfected and will be used for all future syntheses involving alkaline-earth metals. Platinum-rhodium and platinum electrodes have successfully been attached to a specimen of calcium plumbide, using a modified percussion-welding technique.

1-568. STUDY AND DEVELOPMENT OF TRANSISTORIZED MODULAR POWER CONVERTERS. Howard Horsman and Charles Kurkul. Quarterly Progress Report no. 1, 1 July-30 Sept. 1960. United Aircraft Corp., Broad Brook, Conn. Electronics Dept. Hamilton Standard, Rept. no. HSER 2215. 41p. illus. Contract: DA-36-039-SC-85369. AD 250 188. A61-8287.

The purpose of this program is to study techniques of power conversion from low-voltage dc to a higher output voltage for use as dc supply power in existing electronic equipment. It was found early in the program that the type of voltage regulation technique to be used had a great influence on the remainder of the circuit techniques. Therefore, this became the first and most important study in the whole program. With this program resolved, the remainder of the analytical work became a program of detailed examination of: effects of frequency, type of switching circuits, and filter considerations. The final step was then to consider methods of modularizing circuit subsections to obtain the highest degree of interchangeability between converters of different capacities and also between converters and inverters. Some questions on this problem have not been definitely settled, since certain benefits of special designs are lost if the modular requirements for interchangeability have to be met. These are more fully discussed in the detailed study sections. The following conclusions may be drawn from the above study on the development (cont.)

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of transistorized modular power converters: The optimum design scheme for dc-dc conversion will provide a unit relatively lighter in weight, smaller in size and less complex than an optimum dc-ac inverter design of the same power rating. The reduced complexity should also provide a reduction in cost with an increased reliability relative to the optimum inverter design. The voltage source for the power supply is provided by a make-up voltage regulator. The voltage regulator efficiency will be optimized by operating close to the dc supply voltage. Since the voltage regulator output will be varied by pulse-width-modulation control of its made-up portion, operating close to the dc supply level will mean less step-up is required in the regulator. This will result in less drive necessary for its transistor switching which allows an improvement in efficiency and a lowered complexity for the make-up voltage regulator. The requirement for an inverter could be met by the use of a Clapp oscillator and a change in the output filter for both schemes 2 and 3. If an additional degree of output voltage regulation is required, scheme 3 could provide this by amplitude modulating an optimum stepped square waveform. This waveform could be generated by the inclusion of an integrator circuit in the Clapp oscillator module mentioned above. The necessity of preserving this waveform will require the use of a bridge power stage which will raise the cost, however. The bridge circuit will enable the filter to be placed before the transformer resulting in an increased transformer efficiency.

1-569. STUDY OF PHOTOEMISSIVE SURFACES. A.H. Sommer and W.E. Spicer. Final Report, 1 July 1968-31 Mar. 1960. David Sarnoff Research Center, Princeton, N.J. 17p. Contract: DA-44-009-eng-3642. AD 245 373. A61-6201.

The Ag-O-Cs photocathode 1) Ag can be replaced by Au and Pd without appreciable loss in infrared response; Cu produces good red but no infrared response. The metals Tl, Ga and W are ineffective. 2) A minimum amount of Ag is required for infrared response, possibly because individual Ag particles of colloidal dimensions are essential. The outstanding photoelectric properties of the Ag cathode may be associated with the difficulty encountered in aggregating other metals. 3) A minimum amount of Cs-oxide is essential for infrared response. The activated cathode may contain one or more Cs-oxides as well as elementary Cs. 4) Evidence has accumulated that the photo effect in Ag-O-Cs is a volume effect although the low quantum efficiency is compatible with an interpretation as a surface effect.

The Bi-Ag-O-Cs photocathode 1) Cathodes can be activated successfully by any one of the following sequences: (a) Bi-Ag-O-Cs, (b) Bi-O-Ag-Cs, (c) Ag-Bi-O-Cs, (d) Ag-Bi-Cs-O, (e) Bi-O-Cs-Ag. 2) Cathodes can be activated successfully with the oxygen content varying by a factor of approximately ten and the Ag:Bi ratio varying by a factor that may approach twenty.

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By contrast, the absolute amount of Bi required is critical within limits similar to those for Sb in the Cs_3Sb cathode. 3) Attempts to replace the Bi in the Bi-Ag-O-Cs cathode by ^3Ge , Sn, Pb As or Sb were unsuccessful. 4) Attempts to replace the Ag in the Bi-Ag-O-Cs cathode by other metals were completely successful for Au, and to a large extent for Pd and Cu; also for Al under specific processing conditions. 5) In general terms, the Bi-Ag-O-Cs cathode can be regarded as consisting of the small band gap (0.5 ev) material Cs_3Bi whose electron affinity is lowered by the addition of silver or gold and oxygen. The detailed mechanism of this effect is not understood.

1-570. THERMOELECTRIC MATERIALS. Henry E. Wenden, Rasheed Ali Zaidi and Thomas S. Shevlin. Bimonthly Progress Report no. 1, 1 Jan. -29 Feb. 1960. Ohio State Univ. Research Foundation. Engineering Experiment Station, 4 Mar. 1960. 3p. Contract: NObs-78254. RF Proj. 1039. AD 245 406. A61-6188.

This is the first bimonthly progress report concerning a study of ceramic thermoelectric materials in which particular emphasis commensurate with promise is to be placed on liquid thermoelements. Molten vanadates are to be the object of study insofar as they may display, and continue to display, potential merit. Preliminary experiments were conducted to measure approximately the Seebeck coefficients for two sodium vanadate liquids. NV6 produced an emf of approximately 400 microvolts/ $^{\circ}\text{C}$ in the temperature range 600-750 $^{\circ}\text{C}$. In each case, the cooler contact was negative and the hotter contact was positive. Reversal of the temperature gradient direction produced a reversal of polarity. Both melts produced a zero emf at zero temperature gradient or net temperature difference. X-ray patterns before and after heating showed that alteration of the composition occurred during the course of experimentation. Creep of the melt over the boat surfaces was extensive. Highly promising differential Seebeck coefficients are possessed by nominal NV and NV₆ melts.

1-571. THERMOELECTRIC MATERIALS. Henry E. Wenden, Rasheed Ali Zaidi and Thomas S. Shevlin. Bimonthly Progress Report no. 2, 1 Mar. - 30 Apr. 1960. Ohio State Univ. Research Foundation. Engineering Experiment Station. 4 May 1960. Contract: NObs-78254; RF Proj. 1039. 5p. AD 245 907. A61-6189.

This progress report describes the effect of oxidizing and reducing atmospheres on the emf produced by $\text{Na}_2\text{O} \cdot 0.6\text{V}_2\text{O}_5$ (hereafter referred to as NV_6). Differential Seebeck coefficient measurement apparatus has been designed to study the differential Seebeck coefficients of liquid materials while a particular gas atmosphere is circulated or sealed in at the hotter end (top surface) of the material. The apparatus is shown in Fig. 1 and detailed description of its components is given. The experimental procedure consists of dropping individually small particles of NV_6 into the tube, of the apparatus, each being allowed to melt before the next was dropped; filling the tube with NV_6 to the desired height; for the study of emf under different atmospheres, gas was circulated above the molten NV_6 ; the temperature gradient readings and emf readings were taken at regular intervals; after a steady state of emf was reached gas was shut off, and atmosphere sealed in, but readings were continued and after effects recorded.

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The variation in emf in $\text{uv}/^\circ\text{C}$ with time was plotted. Experiments have been carried out under hydrogen, helium, and oxygen atmosphere. With hydrogen atmosphere an emf of about $380 \text{ uv}/^\circ\text{C}$ in NV_6 was reduced to zero in about 25 min and then acquired a steady minimum stable value of about $-32 \text{ uv}/^\circ\text{C}$ in 10 min. With helium atmosphere an emf of $550 \text{ uv}/^\circ\text{C}$ in NV_6 was reduced to minimum value of $110 \text{ uv}/^\circ\text{C}$ in 1-1/2 hrs. The emf then started to increase slowly and stabilized at about $300 \text{ uv}/^\circ\text{C}$ in 16 hrs after the helium circulation was stopped. With oxygen atmosphere an emf of $110 \text{ uv}/^\circ\text{C}$ in NV_6 was increased to a maximum and stable value of $330 \text{ uv}/^\circ\text{C}$ in about four hrs. The emf showed stability even after the oxygen circulation was stopped and the oxygen atmosphere sealed in. The atmosphere dependent tendency to change the energy state results in lowering the energy difference between the exited electrons in the hot and cold end of the tube and hence in reducing the flow of electrons. The net result is the reduction of $\text{emf}/^\circ\text{C}$ temperature difference.

1-572. THERMOELECTRIC MATERIALS. R. G. Breckenridge.
Bimonthly Progress Report no. 7, 28 Jan. - 28 Mar. 1960.
Union Carbide Corp., Parma, Ohio. Parma Research Lab.
15 Apr. 1960. 20p. illus. Contract: NObs-77066, Index no.
NS-058-001. AD 246 217. A61-8293.

This report is essentially a review of work done on thermoelectric materials, accomplishments to date (March 1960) and anticipated activities. The following materials are considered: carbon and graphite materials, refractory nitrides, and alkali metals in their fused halides. Crystal chemistry, measurements of thermal conductivity with a new scanner and the development of prototype axial junction generator are briefly discussed.

1-573. THERMOELECTRIC POWER GENERATION. G. N. Steele.
Presented at the Institute of Radio Engineers Winter Convention on
Military Electronics, Los Angeles, California, 1-3 Feb. 1961.
16p. illus. Pam 61-201.

The idea of solid-state conversion of heat to electrical energy is tantalizing, but in truth, actual devices lag by far predictions for its application. It is the purpose of this paper to put into proper perspective, thermoelectric power conversion, demonstrate what appears to a theoretical limit, and briefly describe devices. Thermoelectric devices are necessarily bulky and inefficient by virtue of the thermoelectric materials from which they are made. Therefore, to develop an understanding of the present state of the art and its projection, this paper primarily discusses the materials.

The author develops his discussion by presenting conclusions and some of the salient features, and by refraining from a rigorous theoretical treatment.

1-574. THERMOELECTRIC POWER GENERATION AND RELATED PHENOMENA. Bimonthly Report no. 8, 7 Mar. - 7 May 1960
E. P. Stambaugh, J. I. Genco, and R. C. Himes. Battelle Memorial Inst., Columbus, Ohio, Rept. no. NS/053-001. 7 July 1960.
21p. illus. AD 245 861. A61-4216.

This eighth bimonthly report on Contract Nobs 77034, entitled "Thermoelectric Power Generation and Related Phenomena," covers the period 7 March 1960 to 7 May 1960. During this period, alloys of nominal molar composition 80 GaAs-20 AlAs were prepared by zone leveling and by crystallization from solution. Resistivity and Hall coefficient were measured as a function of temperature (25°C to approximately 550°) on selected specimens of n- and p-type GaAs-AlAs alloys from previous preparations, and results were plotted (Figures 1 and 2). Some difficulties have arisen in connection with the thermal-diffusivity apparatus. The results obtained are consistently too small when measurements are made on samples whose diffusivity is known from other means. Efforts are being made to track down this trouble. Somewhat tentative results in the investigation of fundamental properties indicate that independent values of the thermoelectric figure of merit may be calculated by using only the differences between electrical properties that have been adiabatically and isothermally measured under properly controlled experimental conditions. Plans for future work in preparation of alloy ingots of
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GaAs-AlAs containing greater than 20 mole percent AlAs, testing the high-temperature-measurement apparatus as well as the thermal diffusivity portion of the work are reported.

1-575. THERMOELECTRICITY. Quarterly Progress Report no. 3.
Westinghouse Electric Corp. Research Labs., Pittsburgh. [1961?] A61-8325.

In the preceding report it was suggested that a compound having an anisotropic effective mass tensor or one in which the anions or cations occur in clusters might have a high figure of merit. During the present quarter a number of these compounds have been prepared and their electrical properties partially investigated. Although none of the compounds investigated were as good as the materials shown on the efficiency charts, it appears that a number of them would give a z of $\sim 0.51-10 \cdot 10^{-3}$ at room temperature if at optimum doping. Another large group of compounds which appears to hold some promise as thermoelectric elements are those compounds having cubic or near cubic structures. Included in this group are some of the better materials; i. e., GeTe, PbTe, and AgSb Te₂. During the quarter a survey of these materials was started with particular emphasis on those substances which have not been prepared before. The work on the proven materials listed on the efficiency charts has been continued. One result was the improvement of the efficiency of MnTe by the discovery that up to 6% Li will dissolve in MnTe and give optimum doped material.

II. MATERIALS

SECTION A - GENERAL

1-576. CHEMISTRY. VOLUME 2. Office of the Chief of Research and Development, Washington, D. C., Army Research Office. Army Research Task Summary, Fiscal Year 1960. 382p. A61-8732, vol. 2.

This document is a summary of project briefs on research in the fields of materials, mathematics, and operations research sponsored by the Army during 1960. Each brief outlines the scope, purpose, approach, and status of the project. Also indicated are the source for additional information, principal investigator, and laboratory or installation where the work is being done. The report includes 442 task summaries.

1-577. MATERIALS TECHNOLOGIES, MATHEMATICS, AND OPERATIONS RESEARCH. VOLUME 6. Office of the Chief of Research and Development, Washington, D. C., Army Research Office. Army Research Task Summary, Fiscal Year 1960. 442p. A61-8732, vol. 6.

This document is a summary of project briefs on research in the field of chemistry sponsored by the Army during 1960. Each brief outlines the scope, purpose, approach, and status of the project. Also indicated are the sources for additional information, principal investigator, and laboratory or installation at which the work is being done. The report includes 382 task summaries.

1-578. SURVEY OF IRRADIATION FACILITIES. Mary Jane Oestmann.
Battelle Memorial Inst. Radiation Effects Information Center,
Columbus, Ohio, REIC rept. no. 16. 28 Feb. 1961. 214p.
Contract: AF 33(616)-7375, (continuation of AF 33(616)-6564),
Proj. no. 4458, Task no. 13008. A61-8576.

This report presents a survey of irradiation facilities generally available to the Air Force and its contractors. Reactors operated at steady-state and pulsed conditions and gamma facilities have been included in this survey. Wherever possible, the information has been tabulated. This report supersedes REIC Reports 7, 7 (first addendum), and 11.

SECTION B - BERYLLIUM AND BERYLLIUM ALLOYS

1-579. BERYLLIUM RESEARCH AND DEVELOPMENT. S. H. Gelles. Quarterly Progress Report, 1 Apr-30 June 1960. Nuclear Metals, Inc., Concord, Mass., Rept. no. NMI-9502. 26 July 1960. 25p. Contract: AF33(616)-7065. 9 refs. A61-6874.

This report describes the work done on the Beryllium Research and Development Program for the period 1 April through 30 June 1960 under Contract AF 33(616)-7065. The objective of this program is to conduct a program aimed at making beryllium useful as an Air Force structural material. There are three major categories in this program: purification, joining, and flow and fracture. Within the three major categories are twelve (12) projects, approximately 40% of which are to be carried out at Nuclear Metals, Inc., the remaining 60% to be subcontracted. Project: 1) Purification of beryllium by iodide decomposition; 2) ultrasonic welding of beryllium; 3) oxide and void distribution in beryllium; 4) role of dislocations in beryllium; 5) surface damage in beryllium; 6) brazing of beryllium; 7) forge welding of beryllium; 8) resistance spot welding; 9) distillation of beryllium; 10) evaluation of products; 11) raising yield strength; 12) aging and strain aging in beryllium.

Contents:

Status of subcontracts Work at Nuclear Metals, Inc.

1-580. BERYLLIUM RESEARCH AND DEVELOPMENT PROGRAM. S. H. Gelles. Quarterly Progress Report, 1 July-30 Sept. 1960. Nuclear Metals, Inc., Concord, Mass., Rept. no. NMI-9505. 10 Nov. 1960. 95p. illus. Contract: AF33(616)-7065, Task no. 73518. 27 refs. A61-6875.

This report describes the progress made on the Beryllium Research and Development Program for the second quarter period, 1 July through 30 September 1960. The objective of the program is to make beryllium more useful as an Air Force structural material. There are twelve (12) projects; eight of these are subcontracted and four are being conducted at Nuclear Metals, Inc. The following is a list of these projects: 1) Purification of beryllium by iodide decomposition; 2) ultrasonic welding of beryllium; 3) oxide and void distribution in beryllium; 4) role of dislocations in beryllium; 5) surface damage in beryllium; 6) brazing of beryllium; 7) forge welding of beryllium; 8) resistance spot welding; 9) distillation of beryllium; 10) evaluation of products; 11) aging and strain aging in beryllium; 12) raising of the yield strength of beryllium.

Contents:

Meeting at Nuclear Metals, Inc., 8 and 9 September 1960
Progress at subcontractor sites
Projects at Nuclear Metals, Inc.

1-581. DEVELOPMENT OF RANDOMLY ORIENTED WROUGHT BERYLLIUM SHEET. F. M. Yans, A. K. Wolff and A. R. Kaufmann. Second quarterly report. Nuclear Metals, Inc., Concord, Mass., Rept. no. NMI-9605. 16 May 1961. 28p. Contract: AF 33(616)-6616. A61-6876.

The purpose of this program is to produce randomly oriented wrought beryllium sheet. This progress report summarizes some of the data obtained in: 1) "Wedge" rolling experiments, whereby the effects of r reduction ratio and annealing heat treatments on the structure and orientation of cold-worked beryllium sheet were studied; 2) texture analysis experiments wherein the original Schulz and the "modified" Schulz methods of texture analysis are discussed; 3) studies to determine the relative importance of several variables in the rolling process as they affect the structure and orientation of beryllium sheet. A brief summary of preliminary conclusions is as follows: 1) Within the ranges studied, the degree of preferred orientation appears to increase almost linearly with reduction ratio; 2) high-temperature (1100°C) short-time (0.1 hour) annealing heat treatments, when applied to warm-worked sheet, appear to reduce to (0001) basal plane texture parallel to the plane of the sheet without increasing the grain size; 3) third-dimensional ductilities as good as those of hot-pressed sheet appear to have been achieved in compression rolled sheet; 4) a low rolling temperature appears to yield a more random texture than a high rolling temperature; (cont.)

1-581. (Cont.)

5) the "original" Schulz (entirely reflection pole figure technique) appears to be the best (0001) texture evaluation method for beryllium sheet generated by this research program.

- 1-582. ELECTROPLATING ON MAGNESIUM AND BERYLLIUM. AN ANNOTATED BIBLIOGRAPHY. Robert C. Gex. Lockheed Aircraft Corp. Missile System Div., Sunnyvale, Calif., Special Bibliography, SB-61-4. Feb. 1961. 31p. AD253 402. 109 refs. A61-8170.

Literature on electroplating on magnesium and beryllium and their alloys is presented. Pretreatment of surfaces for electroplating and testing of electroplated surfaces is included.

- 1-583. GENERAL RESEARCH IN MATERIALS AND PROPULSION. VOLUME II. METALLURGY AND CHEMISTRY. Jan 1959 - Jan 1960. Lockheed Aircraft Corp. Missiles Systems Div., Sunnyvale, Calif., Rept. no. LMSD-288140. Jan. 1960. AD 241 410. A61-1940, vol. 2.

This is a collection of research reports, primarily in the field of beryllium metallurgy, but including two papers on the chemistry of columbium (niobium).

Contents:

Electronic Structure of Beryllium, by G. C. Kuczynski.
Electrical Resistivity of Beryllium, by J. Ho and E. S. Wright.
Plastic Deformation in Beryllium, by E. C. Burke.
Beryllium Analyzed for Trace Impurities by Gamma-Ray Activation, by W. Bradshaw, R. Johnson, and D. Beard.
High-Temperature Corrosion of Beryllium in Air, by W. Bradshaw and E. S. Wright.

1-584. MANUAL FOR BERYLLIUM PROSPECTORS. W. L. Smith.
Battelle Memorial Inst., Defense Metals Information Center,
Columbus, Ohio, DMIC Report 146.
18 Jan. 1961. 30p. 49 refs. A61-6920.

The information in this manual, although no revelation to geologists experienced in beryllium exploration, is selected to be of help to prospectors and to the technically trained who may commercially or otherwise become involved with the search for or applications of, the rare metal.

1-585. REVIEW OF RECENT DEVELOPMENTS IN THE TECHNOLOGY
OF BERYLLIUM. Webster Hodge. Battelle Memorial Inst.
Defense Metals Information Center, Columbus, Ohio, DMIC
memo 123. 18 Aug. 1961. 3p. 9 refs. A61-8579.

Contains a critical review of selected developments in beryllium technology during May, June, and July, 1961. Topics discussed are: the production of sound cast beryllium ingots, shown to require a fast cooling rate; data on purification of beryllium; studies of surface damage and mechanical properties; and the mechanism of corrosion of beryllium in an atmosphere of carbon dioxide with water vapor.

SECTION C - METALS AND ALLOYS

1-586. DEPARTMENT OF DEFENSE TITANIUM SHEET-ROLLING PROGRAM. H. R. Ogden. Battelle Memorial Inst., Defense Metals Information Center, Columbus, Ohio, DMIC Rept. no. 46H. 1 June 1960. 74p. illus. Contract: AF 18(600)-1375. A61-6906.

This report summarizes the progress made on the Titanium Sheet-Rolling Program during the period from 1 Jan. 1959, through Dec. 1959. During this period, the production of the heat-treatable alloys has been completed by one producer and is nearing completion by the other two producers. Three new alloys have been added to the program, Ti-7Al-12Zr, Ti-8Al-1Mo-1V, and Ti-8Al-8Zr-1(Cb+Ta). These are designed to be weldable alpha alloys with high creep strength. Phase II, the development of design data, has been started, with testing well under way. This work is being done on production-aged material by Lockheed Aircraft Corporation, Marietta, Georgia. Two of the seven Phase III contractors have completed their programs, and evaluation is well along for the other five contractors. The two companies who conducted preliminary evaluations of three alloys chose Ti-4Al-3Mo-1V as the most promising alloy for fabrication of parts. All of the Phase III programs are scheduled for completion in 1960.

1-587. DESIGN INFORMATION ON AM-350 STAINLESS STEEL FOR AIRCRAFT AND MISSILES. R. J. Favor, O. L. Deel, and W. P. Achback. Battelle Memorial Inst. Defense Metals Information Center, Columbus, Ohio, DMIC rept. 156. 26 July 1961. 46p. illus. Contract: AF 33(616)-7747. A61-8586.

Tentative room-temperature design-allowable strengths and elevated-temperature design curves are presented for short-time ultimate tensile strength, tensile yield strength, compressive yield strength, ultimate shear strength, bearing ultimate strength, and bearing yield strength.

- 1-588. DESIGN INFORMATION ON TITANIUM ALLOYS FOR AIRCRAFT AND MISSILES. W. P. Achbach and R. J. Favor. Battelle Memorial Inst., Defense Metals Information Center, Columbus, Ohio, DMIC Report 145. 10 Jan. 1961. 84p. illus. Contract: AF 33(616)-7747. A61-4079.

Design allowables are summarized for the commercially important titanium alloys. Information on the all-beta Ti-13V-11Cr-3Al alloy is not yet complete, and little design information is yet available on the super alphas.

- 1-589. DESIGN IMPLICATIONS OF CREEP IN PRESSURIZED CYLINDRICAL SHELLS. Ivan Rattinger and Joseph Padlog. Aerospace Eng., March 1961, vol. 20, no. 3, p. 26-27, 97-108.

This paper develops a method whereby estimates of the creep deformations and failure times of cylindrical shells operating at uniform elevated temperature and constant applied pressure may be rapidly made. Proceeding from creep relationships in terms of the true principal stresses and strains obtained by Nadai on the basis of the theory of plastic flow, the equation for the variation of the nominal creep strain ratios with nondimensional time is derived. The validity of the theory proposed to calculate creep rupture can be substantiated only by comparison with test. Such test-theory comparisons were performed and results obtained indicate reasonable agreement between test and theoretically predicted time-to-stress rupture. The comparison between uniaxial and biaxial creep-rupture strengths is made and general conclusion on the predicted biaxial creep strength for low and elevated temperatures are drawn. The design considerations are presented in two parts. The first reports the analytical procedures for calculating the rupture time and required tank wall thickness for a specific, but simplified, problem. The second discusses, in a general manner, the design complexities introduced by practical problems and suggests methods for their solution.

1-590 THE EFFECTS OF ALLOYING ELEMENTS IN TITANIUM.
VOLUME A. CONSTITUTION.
D. J. Maykuth, H. R. Ogden, and R. I. Jaffee.
Battelle Memorial Inst., Defense Metals Information Center,
Columbus, Ohio, DMIC Report 136A. 15 Sept. 1960. 231p.
illus. Contract: AF 18(600)-1375. 223 refs. A61-6916,
vol. A.

The available information on the constitution and structure of binary and ternary alloys of titanium is presented. Phase diagrams are presented for 37 binary titanium alloys, and partial information is presented for 14 others, as well as for 67 ternary titanium-alloy systems.

1-591. THE EFFECTS OF ALLOYING ELEMENTS IN TITANIUM.
VOLUME B. PHYSICAL AND CHEMICAL PROPERTIES,
DEFORMATION AND TRANSFORMATION CHARACTERISTICS.
D. J. Maykuth, F. C. Holden, et al. Battelle Memorial Inst.,
Defense Metals Information Center, Columbus, Ohio, DMIC
Report 136B. 29 May 1961. 150p. illus.
Contract: AF 33(616)-7747. 169 refs. A61-696, vol. B.

Data on the physical, electrical, and chemical properties of titanium alloys are reviewed. Information is presented on the diffusion of interstitial and substitutional elements. The effects of alloying additions on deformation, recovery, recrystallization, and grain-growth characteristics are analyzed, and transformations are discussed in terms of the reaction kinetics.

- 1-592. THE EMITTANCE OF STAINLESS STEELS. W. D. Wood, H. W. Deem, and C. F. Lucks. Battelle Memorial Inst., Defense Metals Information Center, Columbus, Ohio, DMIC Memo 111. 12 June 1961. 67p. illus. 15 refs. A61-6858.

This memorandum is a compilation of original test data on emittance, reflectance, and absorptance of stainless steels. The data were taken from the literature published during the period 1940-1959 inclusive, and as much of the 1960 literature as could be obtained. The following sources were searched: Chemical Abstracts, Ceramic Abstracts, Metallurgical Abstracts, Nuclear Science Abstracts, and the files of the Defense Metals Information Center (DMIC). The authors have attempted to evaluate these sources of data according to the apparent thoroughness of methods and techniques as described by the various investigators. In many cases the descriptions in the literature are a summary of methods and results, and a complete evaluation is impossible. With these considerations in mind the authors have shown curves which, in their estimation, indicate the most probable values for the various conditions and materials.

- 1-593. THE FACTORS INFLUENCING THE FRACTURE CHARACTERISTICS OF HIGH-STRENGTH STEEL. C. W. Marschall. Battelle Memorial Inst., Defense Metals Information Center, Columbus, Ohio, DMIC Report 147. 6 Feb. 1961. 39p. illus. Contract: AF 33(616)-7747. 30 refs. A61-6921.

This report discusses the various factors, both external and metallurgical, which affect the fracture characteristics of steel.

- 1-594. FIBER-REINFORCED METALS AND ALLOYS.
19 June-18 Aug. 1960. Illinois Inst. of Tech., Chicago.
Armour Research Foundation, Rept. no. ARF 2193-3.
12 Sept. 1960. 13p illus. Contract: Noas60-6081-c, Proj.
no. ARF2193. AD 246 023. A61-2734.

This third bimonthly report covers the period from 19 June to 18 August 1960, for work done on reinforcement of metals by a continuous three-dimensional network of metal fibers. In the steel-silver system, uniform diameter steel wires were chopped and kinked and formed into felts. Silver impregnation was accomplished in vacuo just above the melting point of silver. The composites in the W-Cu system were prepared in the same manner. Resistivity, stress-strain behavior, yield strength, elastic modulus, yield strength, elongation, and ultimate tensile strength, grain size of the matrix, and impact values were measured. Large-diameter fibers do not appreciably affect the current flow, whereas the composites prepared by using 0.0025-in. diameter wire exhibit a linear dependence upon fiber content. Use of large diameter fibers affords virtually no reinforcement of the metal. Yield strength is linearly dependent upon the fiber content, for 0.0025-in. diameter fibers. Ultimate tensile strength is also a linear function of the concentration of small fibers. With the 0.0025-in. wires, the elongation drops linearly with increasing fiber content. The notch toughness increases with increase of fiber content.

- 1-595. INVESTIGATION OF DELAYED-CRACKING PHENOMENON IN
HYDROGENATED UNALLOYED TITANIUM. R. A. Wood,
D. N. Williams, and H. R. Ogden. Battelle Memorial Inst.
Defense Metals Information Center, Columbus, Ohio, DMIC
memo 124.
30 Aug. 1961. 18p. 18 refs. A61-8580.

Several instances of delayed cracking in unalloyed titanium aircraft components have been reported in the last few years. In some cases a high interstitial content was observed in the metal. Hydrogen interstitials were suspected to be causing the embrittlement. Accordingly, tests were undertaken to determine what hydrogen content would result in the delayed cracking of commercial titanium grades. The results of the tests are presented. It is concluded that strain-aging embrittlement does not occur in unalloyed titanium having up to 0.38 wt % oxygen content with as much as 160 ppm hydrogen content; however, a noticeable effect of hydrogen on notch sensitivity of the materials was noted. In one case of cracking where hydrogen interstitials were concentrated at the fractures, it was concluded that a stress-relief annealing treatment which would redistribute the hydrogen concentrations would offer an effective remedy.

1-596. OXIDATION OF TUNGSTEN. V. D. Barth and G. W. P. Rengstorff.
Battelle Memorial Inst. Defense Metals Information Center,
Columbus, Ohio, DMIC rept. 155. 17 July 1961. 174p. illus.
Contract: AF 33(616)-7747. 186 refs. A61-8585.

This report presents a detailed review of available information on the oxidation of tungsten and its alloys. Present knowledge of tungsten oxidation is incomplete, and the state of the art has not yet reached the point where final conclusions can be drawn. Because of the current importance of the subject, however, the consolidation of the widely scattered references appears worthwhile. Tungsten is relatively inert below 700°C. As the temperature is increased above this level, however, oxidation becomes progressively more rapid, reaching catastrophic rates at temperatures around 1200°C and above. Various theories for the mechanism and rates of tungsten oxidation at different temperatures are reviewed, and the effect of pressure and water vapor on the stability of tungsten oxides is discussed in detail. The elevated-temperature reactions of tungsten with other materials, such as refractory oxides, and with gases other than oxygen also are covered. Some information on the protection of tungsten by alloying and coating is included; however, the subject of protective coatings is covered in more detail in another DMIC report now in preparation.

1-597. PHYSICAL AND MECHANICAL PROPERTIES OF COMMERCIAL MOLYBDENUM-BASE ALLOYS. J. A. Houck.
Battelle Memorial Inst., Defense Metals Information Center,
Columbus, Ohio, DMIC Report 140. 30 Nov. 1960. 174p. illus.
Contract: AF 18(600)-1375. 63 refs. A61-6917.

A compilation of the more important physical and mechanical properties of molybdenum and commercial molybdenum-base alloys is presented. Included among the alloys are: Mo-0.5Ti, Mo-0.5Ti-0.08Zr (TZM), Mo-0.05Zr, Mo-30W, Mo-50W, and Mo-1.25Ti-0.5Zr-0.15C (TZC)

- 1-598. PHYSICAL PROPERTIES OF SOME NICKEL-BASE ALLOYS.
M. E. Langston and C. H. Lund. Battelle Memorial Inst.,
Defense Metals Information Center, Columbus, Ohio, DMIC
Report 129. 20 May 1960. 146p. illus. Contract:
AF 18(600)-1375 A61-6915.

The available physical properties of 33 nickel-base alloys are tabulated along with their respective chemical compositions and a brief general description of each alloy, its uses, and available forms. The 33 representative alloys are divided into the following six groups:

- Group I. Nickel-Copper
- Group II. Nickel-Silicon
- Group III. Nickel-Chromium
- Group IV. Nickel-Chromium-Iron
- Group V. Nickel-Chromium-Cobalt
- Group VI. Nickel-Molybdenum

- 1-599. A REVIEW OF BENDING METHODS FOR STAINLESS STEEL
TUBING. C. T. Olofson. Battelle Memorial Inst., Defense
Metals Information Center, Columbus, Ohio, DMIC Report
150. 2 Mar. 1961. -52p. illus. Contract: AF 33(616)-7747.
12 refs. A61-6923.

This report describes the applications and limitations of ram bending, roll bending, rotary compression bending, and rotary draw bending. The latter method is the most widely used in the aircraft industry, and the discussion deals mainly with this process.

1-600. REVIEW OF RECENT DEVELOPMENTS IN THE EVALUATION OF SPECIAL METAL PROPERTIES. J. E. Campbell. Battelle Memorial Inst. Defense Metals Information Center, Columbus, Ohio, DMIC memo 128. 27 Sept. 1961. 8p. 7 refs. A61-8584.

Contains newly available information between June and August 1961 on evaluation of mechanical properties of metals. Topics discussed are as follows: evaluation of titanium for liquid-hydrogen tankage, including a tabulation of pertinent mechanical properties; effects of small cracks in reducing the strength of tensile specimens; and determination of hydrogen embrittlement in metals.

1-601. REVIEW OF RECENT DEVELOPMENTS IN THE TECHNOLOGY OF MOLYBDENUM AND MOLYBDENUM-BASE ALLOYS. J. A. Houck. Battelle Memorial Inst. Defense Metals Information Center, Columbus, Ohio, DMIC memo 129. 6 Oct. 1961. 3p. 6 refs. A61-8415.

A critical review of developments in molybdenum technology between 30 June and 30 September 1961. Developments discussed are: production and mechanical properties of high purity molybdenum with room temperature ductility; electron-beam melting of molybdenum; increases in high-temperature tensile and creeping strengths of arc-cast molybdenum attributed to fabrication at true hot-working temperatures; difficulties in attempts to cast a complex alloy based on 75Mo-25W and 50Mo-50W; transition temperatures, tensile and crack-propagation of Mo-0.5Ti and Mo-0.5Ti-0.08-Zr (TZR) alloys.

- 1-602. REVIEW OF RECENT DEVELOPMENTS IN THE TECHNOLOGY OF TUNGSTEN. V. D. Barth. Battelle Memorial Inst. Defense Metals Information Center, Columbus, Ohio, DMIC memo 127. 22 Sept. 1961. 7p. 16 refs. A61-8583.

A brief review of major developments in the technology of tungsten between May and August, 1961. The following topics are discussed: plasma-arc spraying of tungsten powder to form forgeable forms; consolidation and fabrication by gas-pressure bonding; explosive forming and consolidation; casting of tungsten and tungsten-molybdenum alloys; the properties of "single crystal" tungsten bars; electron-beam melting; extrusion studies; production of porous tungsten disks for use as ionizers in rocket engines; production of forged-tungsten nozzle-throat inserts; a number of studies about the oxidation and protection of tungsten; mechanical properties of tungsten at high temperatures; effect of surface conditions on ductility; and a comprehensive study of the effects of dispersoids on the properties of tungsten.

- 1-603. A REVIEW OF RECENT DEVELOPMENTS IN TITANIUM AND TITANIUM ALLOY TECHNOLOGY. R. A. Wood. Battelle Memorial Inst. Defense Metals Information Center, Columbus, Ohio, DMIC memo 126. 15 Sept. 1961. 6p. 18 refs. A61-8582.

Discussion of new developments in titanium metallurgy between June and August 1961. Major interest currently is centered on Ti-13V-11Cr-3Al all-beta alloy and the Ti-8Al-1Mo-1V, Ti-7Al-12Zr, and Ti-5Al-5Sn-5Zr super alpha alloys; the report outlines and discusses the importance of recent reports on the properties and use of these alloys. Selected properties of the super alpha alloys are shown in a table.

- 1-604. **SOME QUANTITATIVE ASPECTS OF FATIGUE OF MATERIALS.**
Harold N. Commings. Curtiss-Wright Corp., Propeller Div.,
Caldwell, N. J., WADD TR-60-42.
July 1960. 278p. Contract: AF 33(616)-6552, Proj. no. 7381.
AD247 115. A61-8592.

The purpose of this report is to provide research and design engineers and metallurgists with data about the room-temperature fatigue properties of structural materials, and a few high-temperature properties, as determined in the laboratory. Since these properties can be changed so radically by so many different variables, the report presents for each item all of the special conditions under which its reported fatigue properties are valid--insofar as it is stated in the reference. The information gathered is presented in tables, figures, and brief discussion. An index is furnished. The following types of materials are discussed: steels, heat resistant alloys, aluminum alloys, magnesium alloys, titanium alloys, some plastic and wood laminates, and a few high temperature properties of beryllium.

- 1-605. **STATISTICAL ANALYSIS OF TENSILE PROPERTIES OF HEAT-TREATED Ti-4Al-3Mo-1V AND Ti-2.5Al-16V SHEET.**
G. H. Beatty and H. R. Ogden. Battelle Memorial Inst., Defense
Metals Information Center, Columbus, Ohio, DMIC Rept. no. 46J.
6 June 1961. 39p. illus. Contract: AF 33(616)-7747.
A61-6907.

The tensile properties (ultimate strength, yield strength, and elongation) of Ti-4Al-3Mo-1V and Ti-2.5Al-16V, as produced under the Titanium-Alloy Sheet-Rolling Program, are examined statistically. When solution-treated and aged, Ti-4Al-3Mo-1V has a higher ultimate strength than does Ti-2.5Al-16V, but the two alloys are about even in yield strength and elongation. When solution treated, Ti-2.5Al-16V is unquestionably the stronger. These conclusions are independent of producer. There is not much difference in the same alloy produced by different companies.

- 1-606. A SUMMARY OF THE THEORY OF FRACTURE IN METALS.
J. W. Spretnak. Battelle Memorial Inst. Defense Metals
Information Center, Columbus, Ohio, DMIC rept. 157.
7 Aug. 1961. 63p. illus. Contract: AF 33(616)-7747.
50 refs. A61-8587.

The theoretical strength of metals, based on atomic forces, is in the order of 100-1000 greater than that observed. The various reasons for this discrepancy between theoretical and observed strength are discussed in detail, but the more important ones are 1) lattice imperfections, 2) the fact that real metals are polycrystalline aggregates, 3) crystalline anisotropy, and 4) the ability of metals to deform by shear. Plastic flow, particularly heterogeneous plastic flow, is intimately associated with crack initiation. The precise conditions under which plastic flow ceases and bond rupturing (cracking) begins are not completely understood. The body-centered cubic lattice has geometric characteristics that make it particularly susceptible to fracture with little or no preceding plastic flow. Multidirectional stress fields, both microscopic and macroscopic, affect the degree of plastic deformation that precedes crack initiation. The theory of fracture as it exists today is reviewed. Though incomplete in many respects, it can be helpful in understanding the behavior of metal structures.

- 1-607. STRUCTURAL DAMAGES IN THERMALLY CYCLED RENÉ 41
AND ASTROLOY SHEET MATERIALS.
D. P. Moon, J. A. Van Echo, et al. Battelle Memorial Inst.,
Defense Metals Information Center, Columbus, Ohio, DMIC
Report 126. 29 Feb. 1960. 23p. illus. Contract:
AF 18(600)-1375. A61-6914.

Stress-rupture life at 1650°F and tensile properties at room temperature and at 1400°F were used to determine the extent of structure damage in thermally cycled René 41 and Astroloy sheet materials. Solution-treated and aged René 41 was tested both in the heat-treated condition and after exposure to 10 or 100 thermal cycles between 1350°F and 1750°F or 1875°F. All of the conditions of thermal-cycling exposure caused at least some loss in the strength of this material. Metallographic examination indicated that overaging was primarily responsible for the damage at 1750°F, and resolution of the Ni₃(Al, Ti) precipitate and depletion of the alloy by surface oxidation were the damaging mechanisms at 1875°F. Solution-treated and aged Astroloy was evaluated in the same manner in the heat-treated condition and after 10 thermal cycles between 1350°F and 1875°F. No loss of strength was incurred by this exposure, but overaging had taken place and would probably have caused structural damage with further exposure.

1-608. TITANIUM ALLOY FORGINGS. H. J. Henning and
P. D. Frost. Battelle Memorial Inst., Defense Metals
Information Center, Columbus, Ohio, DMIC Report 141.
19 Dec. 1960. 89p. illus. Contract: AF 18(600) 1375.
A61-6918.

This report is a summary of current information on the availability, metallurgical and dimensional quality, and mechanical properties of titanium die forgings. Detailed data on typical forgings are presented, and some forging techniques are discussed.

SECTION D - REFRACTORY MATERIALS

1-609. MECHANICAL PROPERTY SURVEY OF REFRACTORY NON-METALLIC CRYSTALLINE MATERIALS AND INTERMETALLIC COMPOUNDS. William D. Smiley, Leon E. Sobon, et al. Stanford Research Inst., Menlo Park, Calif., WADC TR 59-448. Jan 1960. 308p. illus. Contract: AF 33(616)-5907, Proj. no. 7021. AD234 775. 1201 refs. A61-8501.

In this program, the literature on the mechanical properties of nonmetallic polycrystalline compounds and intermetallic compounds with melting points above 1500°C was surveyed. The theoretical concepts of flow and fracture were reviewed. It was determined that the mechanical properties of many potential high-temperature materials have not been evaluated. Data for those which have been partially evaluated were in most cases either incomplete, or meaningless because of failure to associate the data with the structure, purity, and thermal history of the material. It was concluded that the intermetallic compounds which are brittle at room temperature and slightly ductile at high temperature (where some of them are also stronger) are more worthy of future study than the much worked-over oxides and interstitial compounds. Another conclusion of this study was that conventional parameters, such as tensile strength, etc., may not be of value for designing high-temperature structural components, and that data from tests closely simulating actual use conditions are necessary before the designer can confidently use brittle materials. An exhaustive bibliography (cont.)

1-609. (Cont.)

of 1201 references is included. Additional research is warranted in certain areas, where there is either a lack of pertinent data on compound classes, or a need for more fundamental information on prevention and cure of imperfections. Materials included in this report are oxides, mixed oxides, carbides, borides, nitrides, intermetallics, sulfides, rare earths, and nonmetallic crystalline materials.

- 1-610. PHYSICAL AND MECHANICAL PROPERTIES OF COLUMBIUM AND COLUMBIUM-BASE ALLOYS. E. S. Bartlett and J. A. Houck. Battelle Memorial Inst., Defense Metals Information Center, Columbus, Ohio, DMIC Report 125. 22 Feb. 1960. 63p. illus. Contract: AF 18(600)-1375. 69 refs. A61-6913.

The current state of knowledge of the physical and mechanical properties of columbium and its alloys is reviewed in this report. Columbium has good potential as an alloying base because of its low neutron-capture cross section (reactor applications) and high melting point, and related potential high-temperature strength (air-and space-vehicles structural applications). Pure columbium is soft and ductile and does not possess good strength at temperatures above 1600°F. Elevated-temperature strengthening is accomplished by solid-solution-strengthening (with tungsten or molybdenum) and dispersion-hardening (zirconium plus carbon) mechanisms. The effects of singular and combined alloying additions on fabricability and low- and high-temperature strength are discussed. The properties of current commercial and advanced laboratory alloys are correlated with strengthening mechanisms. A Cb-15W-5Mo-1Zr-0.05C-0.05 O alloy, with 100-hr, 2200°F rupture stress of 17,000 psi, is the most promising alloy to be developed to date.

- 1-611. REFRACTORY MATERIALS. Part II--HIGH-TEMPERATURE BEHAVIOR. Robert I. Jaffee and Daniel J. Maykuth. Aero/Space Eng., July 1960, vol. 19, no. 71. p. 39-45.

This paper deals with mechanical behavior of refractory materials at elevated temperatures. This includes the thermally activated process of diffusion, creep, and recrystallization. The physical properties governing thermal stress are compared. The course of future developments in this very new field is briefly outlined. Elevated-temperature creep of metals occurs by a process of dislocation climb, which requires thermal activation and diffusion of atoms. The greater the activation energy and the lower the temperature, the lower will be the creep rate, according to the exponential function. Materials with greater melting points offer the greatest potential for development of high-temperature strength. The elevated-temperature strength of refractory metals may be improved by cold work, solid-solution alloying, interstitial solution, and dispersions of insoluble compounds. The elevated temperature strength of metals can be considerably enhanced by alloying. Strengthening through alloying also appears possible for some of the intermetallic compounds. Metallic materials have by far the best strengths up to temperatures of about 2400°C. The modulus of elasticity for metals is highest for the heavy metals in the higher period group of the periodic table, like tungsten, molybdenum, rhenium, etc. The

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1-611. (Cont.)

refractory metals in Group V have considerably lower moduli of elasticity, with the lighter metal columbium having the lowest modulus. The refractory metals are notable for their high conductivity values and are followed closely by graphite, although the conductivity of graphite drops off significantly at the higher temperature. It can be expected that the present fairly elementary stage of development of refractory materials to be considerably advanced over the next several years will be in the following directions: superior elevated-temperature strength, development of coatings, fabricating processes for large sheets, forging and extrusions, and development of products of aircraft quality. Future improvements in the performance of refractory materials can be confidently expected as a result of considerable research effort in the refractory-materials field.

SECTION E - PROTECTIVE FINISHES AND COATINGS

1-612. THE EFFECT OF NUCLEAR RADIATION ON PROTECTIVE COATINGS. Ramona A. Mayer, Norman J. Broadway, and Stephen Palinchak. Battelle Memorial Inst. Radiation Effects Information Center, Columbus, Ohio, REIC rept. no. 13. 15 July 1960. 16p. Contract: AF 33(616)-7375, (continuation of AF 33(616)-6564), Proj. no. 2133, Task no. 60001. 12 refs. A61-8573.

This report presents the state of the art on the effects of nuclear radiation on protective coatings through May 1960. The report summarizes the available radiation-effects information on various coatings and coating systems, including pigments. Information on electrical and thermal insulation has not been included. The report is intended to be sufficiently inclusive to make it valuable as a guide on effects which can be anticipated from nuclear radiation on protective coatings. Coatings generally considered for present and future use in the aviation industry are based on the following materials: phenolics, furanes, alkyds, silicone alkyds, vinyls, nitrocellulose, neoprene, styrene-butadiene, and epoxy. Coating and paints prepared from all these resins except polyvinyl chloride and nitrocellulose appear to be satisfactory for use after exposure to 8.7×10^{10} ergs g^{-1} (C) (1×10^9 roentgens). The vinyl and nitrocellulose resins are at least resistant to radiation and are only satisfactory to the 10^{10} ergs g^{-1} (C) exposure. Additives such as pigments, plasticizers, and other coating (cont.)

1-612 (Cont.)

ingredients, as well as the type of surface on which the coating is applied, influence the radiation stability of the coating. Coatings which are highly pigmented are generally more resistant to radiation than similar gloss coatings containing lesser amounts of pigments. Carbon black inhibits damage due to radiation, while toluidine red has little effect. Titanium dioxide appears to accelerate radiation damage. Coating systems, especially lacquers, employing wash primers become embrittled, and poor adhesion between the coating system and the substrate occurs. Studies show that Alkaloy (furane base) and Epon-395 (epoxy base) coatings have good chemical resistance after exposure to approximately 8.7×10^{10} ergs g^{-1} (C) (10^9 roentgens). Amphesive-801, a modified phenolic, loses its resistance to sodium hydroxide and the organic solvent, hexone (methyl isobutyl ketone), as a result of irradiation. Epon-1001 also loses its resistance to hexone when irradiated. On the other hand, Epon-395 becomes resistant to sulfuric and hydrochloric acid as a result of gamma radiation.

1-613 THE EMITTANCE OF COATED MATERIALS SUITABLE FOR ELEVATED-TEMPERATURE USE. W. D. Wood, H. W. Deem, and C. F. Lucks. Battelle Memorial Inst., Defense Metals Information Center, Columbus, Ohio, DMIC Memo 103. 4 May 1961. 136p. illus. 12 refs. A61-4854.

This memorandum is a compilation of original test data on emittance and reflectance of coated materials suitable for use at elevated temperatures. The data were taken from the literature published during the period 1940-1959, inclusive, and from as much of the 1960 literature as could be obtained. The following sources were searched: Chemical Abstracts, Ceramic Abstracts, Metallurgical Abstracts, Nuclear Science Abstracts, and the files of the Defense Metals Information Center (DMIC). The authors have made an effort to evaluate these sources of data according to the apparent thoroughness of methods and techniques as described by the various investigators. In many cases the descriptions in the literature are a summary of methods and results and a complete evaluation is impossible. With these considerations in mind the authors have confined their evaluations to showing curves which, in their estimation, indicate the most probable values for the various conditions and materials.

1-614. MATERIALS EFFECTS IN SPACECRAFT THERMAL CONTROL. Roger E. Gaumer, Francis J. Clauss, et al. Lockheed Aircraft Corp., Missile System Div., Sunnyvale, Calif., Rept. no. LMSD-704019. Nov. 1960. 20p. illus. A61-3047.

Techniques of thermal control used at Lockheed to regulate internal temperature of satellites rely upon passive radiation in which the desired average orbital temperature is achieved by balancing the absorptivity of the surfaces for solar radiation with their emissivity for infrared radiation. Solar reflectors are used to maintain very low equilibrium temperatures or to eliminate large amounts of internally generated power, while solar absorbers are used for exactly opposite reasons. Flat absorbers and flat reflectors are used to minimize orbital temperature fluctuations. Solar absorptivity and infrared emissivity have been obtained for 500 materials; values of these constants for the most promising materials are tabulated. Black paints and anodizing treatments resulting in black matte surfaces are good flat absorbers, while aluminum-pigmented silicone paint is a good flat reflector. Highly polished metallic surfaces are used as solar absorbers. Lockheed has had difficulty in finding a good solar reflector. White paint is a good approximation to a reflector, but its reflectivity is not high enough for many applications, such as attaining temperatures sufficiently low for infrared

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sensors to operate efficiently. Considerable effort is being expended in an effort to find a better reflector. Radiative surfaces must withstand both normal pre-launch handling and deterioration, and be stable during the ascent phase. They must also be stable under orbital conditions of high energy radiation and high vacuum. It has been found that organic-vehicle paints turn yellow, with consequent loss of reflectivity, under ultraviolet irradiation in high vacuum; acrylic-base paints are most resistant. Inorganic-vehicle paints appear to have better resistance to yellowing. Experiments in progress indicate that silicate and phosphate paint vehicles, and zircon pigment, are the most promising.

SECTION F - ELECTRIC, ELECTRONIC, AND MAGNETIC MATERIALS AND DEVICES

1-615. THE EFFECT OF NUCLEAR RADIATION ON CAPACITORS.
C. L. Hanks. Battelle Memorial Inst. Radiation Effects
Information Center, Columbus, Ohio, REIC rept. no. 15.
15 Feb. 1961. 40p. illus. Contract: AF 33(616)-7375,
(continuation of AF 33(616)-6564), Proj. no. 4458, Task
no. 13008. 20 refs. A61-8575.

This report presents information to cover the state-of-the-art knowledge on the effects of nuclear radiation on capacitors of various types. Data are presented for ceramic, glass, mica, paper, and plastic dielectric capacitors, and for electrolytic capacitors. Ceramic capacitors have shown various degrees of radiation sensitivity. Changes in capacitance have varied from less than 1% to approximately 20% above the initial values during irradiation. These changes are not permanent, and the capacitors do recover approximately to their original state when removed from the radiation environment. The capacitance of the general-purpose ceramic capacitors also changes when these capacitors are subjected to nuclear radiation. These changes are considered negligible when compared to the wide tolerances associated with these units. Glass capacitors have demonstrated the greatest resistance to nuclear radiation, with transient capacitance increases of between 0.7 and 2.5% observed. Permanent damage has resulted in capacitance changes of less than 0.5%. These changes indicate that glass capacitors would not be acceptable for tuned-circuit applications that (cont.)

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require precision capacitors. However, they should prove acceptable in other applications where this precision is not required. Mica capacitors have shown various degrees of radiation resistance. A small change in capacitance, in either direction, during irradiation is typical of these units. Postirradiation measurements indicate that these changes are generally permanent with some capacitors suffering visible damage in the form of casing fractures. Experiments with paper and oil-impregnated paper capacitors show them to be more sensitive to radiation than the inorganic types by factors of one hundred to a thousand. The plain paper dielectric is more suitable than the oil-impregnated paper as the oil evolves gas and subsequently causes distortion and/or rupture of the capacitor case. Radiation damage has also caused large changes in the capacitance of paper capacitors. Plastic dielectric capacitors are less satisfactory than the inorganic dielectric types by approximately a factor of ten. Radiation studies on electrolytic capacitors have indicated that both tantalum and aluminum electrolytic units may be capable of surviving extended exposure to intense radiation. These studies have also shown that the tantalum capacitors are the more resistant to radiation damage; however, tantalum units do offer a biological hazard due to activation by thermal-neutron bombardment. The radiation that results from this activation has a half-life

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of 111 days as compared with 2.3 minutes for aluminum. Radiation-included damage to capacitors may also be exhibited by increases in dissipation factor and decreases in leakage resistance. All of these effects from radiation, including capacitance change, are a result of the degradation of the dielectric. The greatest amount of leakage-resistance change is of a transient nature and is caused by gamma-induced ionization in air spaces within the capacitor or within the dielectric material.

1-616. THE EFFECT OF NUCLEAR RADIATION ON ELECTRON TUBES AND TUBE MATERIALS. W. E. Chapin. Battelle Memorial Inst. Radiation Effects Information Center, Columbus, Ohio, REIC rept. no. 14. 15 Feb. 1961. 36p. Contract: AF 33(616)-7375 (continuation of AF 33(616)-6564), Proj. no. 4458, task no. 13008. 33 refs. A61-8574.

This report contains information accumulated from studies of radiation effects as reported for electron tubes and tube materials during the past 8-10 years by numerous researchers on radiation effects. These studies indicate that the primary damage mechanism which limits prolonged use or storage of electron tubes in high-intensity fluxes is the failure of the glass envelope. Much has been written concerning failures occurring in the glass-to-metal seals. These damages were observed at integrated neutron fluxes in the range of 10^{15} to 10^{16} (nv)₀t for most borosilicate envelopes and Kovar seals. Boron-free glasses are more radiation resistant and can withstand integrated fluxes as high as 10^{18} (nv)₀t. Tubes necessitating large glass envelopes, such as power tubes, are more prone to radiation damage due to their size. Miniature and subminiature tubes require smaller sealing areas and use less glass, thus enabling the tube to withstand more prolonged exposures. An increased interest is being shown for ceramic tubes, and a limited amount of research in radiation effects is being conducted. Ceramic tubes exhibit one disadvantage insofar as their susceptibility to radiation damage. (cont.)

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The level of residual radioactivity after irradiation is much higher than for the glass-tube type. Use of ceramic envelopes has removed the problem of fractures due to radiation, but the seals being used contain elements that retain radioactivity to the point that it is suspected that life characteristics and operation would be greatly affected. Gamma radiation does not cause any appreciable effect on most electron tubes. The exception to the case is applicable mainly to tubes that rely on light transmission. Gamma radiation has been associated with discoloration of the glass envelope, and ultimately affects the sensitivity of various photomultiplier devices. Magnetrons and other similar devices are not suited for use in high-intensity radiation fields because they are extremely sensitive to minute changes in the glass structures of their envelopes. In most experiments, these electron devices became inoperable immediately upon irradiation.

1-617. THE EFFECT OF NUCLEAR RADIATION ON ELECTRONIC COMPONENTS. D. J. Hamman, W. E. Chapin, et al. Battelle Memorial Inst. Radiation Effects Information Center, Columbus, Ohio, REIC rept. no. 18. 1 June 1961. 140p. illus. Contract: AF 33(616)-7375 (continuation of AF 33(616)-6564), Proj. no. 1448, Task no. 13008. 109 refs. A61-8578.

This report presents information which covers the state-of-the-art of knowledge on the effects of nuclear radiation on basic electronic parts that is available in the REIC files. As such, it represents a summary of information accumulated within the past year plus information previously reported in REIC Reports Nos. 12, 14 and 15. Some information pertinent to this compilation of radiation effects was also obtained from REIC Technical Memorandums Nos. 7, 14, and 20. This report presents component results that are grouped as to family within each component class type. The results presented in the report are intended to provide a basis for judging the merits of the parts when they are to be used in circuitry that will be exposed to a radiation environment. The primary damage mechanism which limits prolonged use or storage of electron tubes in high-intensity radiation fields is the failure of the glass envelope. The critical area in which most problems occur is the glass-to-metal seals. Damage indications were observed at integrated mixed neutron fluxes in the range of 10^{15} to 10^{16} n cm⁻².

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for most borosilicate envelopes and Kovar seals. Boron free glasses show more resistance to radiation damage and can withstand integrated mixed fluxes as high as 10^{18} n cm⁻²; however, there are indications that an increase in fragility can be expected. Subminiature and miniature vacuum tubes exhibit more resistance to nuclear damage to their envelopes than other glass-type tubes.

1-618. THE EFFECT OF NUCLEAR RADIATION ON SEMICONDUCTOR DEVICES. F. J. Reid.
Battelle Memorial Inst. Radiation Effects Information Center,
Columbus, Ohio, REIC rept. no. 10. 30 Apr. 1960. 26p.
Contract: AF 33(616)-6564 (continuation of AF 33(616)-5171),
Proj. no. 2133, Task no. 60001. 36 refs. A61-8572.

This report presents the current state of the art on the effects of nuclear radiation on semiconductor devices. The report summarizes the information on permanent radiation effects observed for various silicon and germanium transistors, diodes, and rectifiers and presents what information is available on infrared detectors, photovoltaic devices, thermoelectric devices, tunnel diodes, SiC rectifiers, and GaAs Zener reference elements. Information on transient radiation effects has not been included. The report is intended to be sufficiently inclusive to make it valuable as a guide on effects which can be anticipated from nuclear radiation on electronic circuits utilizing semiconductor devices. Nuclear radiation causes changes in three parameters which affect semiconductor devices; namely, conductivity, minority-carrier lifetime, and surface recombination velocity. Reactor irradiation studies of transistor- and diode-type devices of germanium and silicon (exclusive of tunnel diodes) have received the most attention by various investigators in the field. In the case of junction transistors the

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greatest source of degradation is the effect of radiation on volume recombination. For a given degradation in current gain a germanium transistor requires fast neutron exposures of one or two orders of magnitude in excess of that which will produce the same degradation in a silicon transistor of comparable design. The maximum possible limits for commonly employed germanium and silicon transistors are integrated fluxes of the order of 10^{16} and 10^{15} fast n cm^{-2} , respectively. For applications which require the use of thicker-base-region devices, the level of radiation resistance is decreased. It appears that a 10-watt, non-linear, four-region semiconductor switch will operate in a radiation field where the integrated fast-neutron flux exceeds 10^{14} n cm^{-2} . Transistorized circuits have been operated under integrated fast-neutron exposures in the range of 10^{15} to 10^{16} n cm^{-2} . Zener reference elements of silicon are noticeably affected by neutron irradiations in the decade of 10^{14} to 10^{15} n cm^{-2} with changes of approximately 1% being observed in the reference voltage. GaAs Zener reference elements appear to be stable during irradiation to 10^{15} n cm^{-2} . The results of reactor irradiations of germanium, and GaAs tunnel diodes indicate that these high-carrier-concentration devices have upper exposure limits in the range 10^{16} to 10^{17} fast n cm^{-2} . Silicon carbide rectifiers have shown radiation tolerances greater than 5×10^{16} fast n cm^{-2} . Only a limited amount of

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irradiation information is available for semiconductor devices other than diodes and transistors. Infrared detectors including PbS, PbSe, and InSb have been found to have upper exposure limits in the range 10^{13} to 10^{14} fast n cm^{-2} . However, thermistor bolometers have been found to be useful in the range 10^{15} to 10^{16} fast n cm^{-2} .

SECTION G - PLASTICS AND COMPOSITES

- 1-619. EFFECTS OF AGING ON THE COMPRESSIVE PROPERTIES OF GLASS-FABRIC-BASE POLYESTER LAMINATES. Kenneth E. Kimball. Forest Products Lab., Madison, Wis. and Bureau of Naval Weapons. Rept. no. 1882, 1961 3p. Contract: DO 33(616)58-1 and 33(616)-61-06 and Bureau of Naval Weapons Order no. 19-61-8041-WEPS. A61-8741.

Information was obtained on the effect of storage for 9 years in a normal atmosphere on the compressive properties of glass-fabric-base plastic laminates made with a typical polyester resin. In thickness and specific gravity, the specimens were comparable. Compressive stiffness and a maximum strength had not changed by an appreciable amount after 9 years in storage. Proportional limit strength was lower after aging, but this may not be significant. In general, it can be concluded that storage for 9 years under normal conditions did not produce any significant changes in the compressive properties of typical glass-fabric-base polyester resin laminates.

- 1-620. PLASTICS. AN ASTIA REPORT BIBLIOGRAPHY. Armed Services Technical Information Agency, Arlington, Va. Aug. 1961. 698p. AD 259 000. 3926 refs. A61-8739.

References pertaining to plastics were selected from all unclassified documents cataloged by ASTIA from 1953 through 1960. The subject content is presented under the following headings: acrylics, adhesives, cellulose, coatings, elastomers, expanded plastics, epoxides, fibers and textiles, fluoroplastics, heat resistant polymers, laminates, optical plastics, phenolics, polyesters, polyethylenes, polymer solutions, polymers, polystyrenes, resins, silicon base, vinyls, general and miscellaneous. (References to documents cataloged prior to 1953 are identified by ATI and TIP numbers and are listed in ASTIA bibliographies AD 26 266, AD 65 082, and AD 59 706.)

- 1-621. **PREDICTING THE STRENGTH OF REINFORCED PLASTIC LAMINATES WITH TEMPERATURE GRADIENTS.**
Kenneth H. Boller. Forest Products Lab., Madison, Wis. and University of Wisconsin. Rept. no. 1881. June 1961. 11p. illus. Order nos. NAer 01967 and 19-61-8019-WEPS. A61-8740.

A simple theoretical method was developed to predict the strength of reinforced plastic laminates when thermal gradients exist through the thickness. Theoretical values are compared with experimental data from compression and tension tests. The observed strength was equal to or slightly greater than what the theory predicts, so it was concluded that the theory is conservative and useful for the solution of thermal gradient problems.

- 1-622. **RECENT DEVELOPMENTS IN CASTING RESINS AND TECHNOLOGY FOR ELECTRICAL ENCAPSULATING APPLICATIONS (U).** Arnold M. Molzon. Picatinny Arsenal. Plastics Tech. Evaluation Center (PLASTEĆ). Rept. no. 3 Nov. 1960. 31p. illus. AD 247 865. 90 refs. A61-8437.

Recent developments in plastic casting resins, processing techniques, and test methods for electrical encapsulation applications are summarized. Plastic materials covered include epoxy, silicone, polysulfide, polyurethane, polyester, and hydrocarbon. Advances in electrical testing techniques have been largely due to the use of sensing devices encapsulated in the resin and the determination of parameters both during and after resin hardening. Instrumentation has been reported for determining the existence and magnitude of thermal stresses in casting resins during and after cure; the electrical properties of the resins during and after cure; thermodynamic properties, such as rate of polymerization, extent of polymerization, and over-all activation energies; and thermal properties, such as specific heat and second-order transition temperature. Advances in encapsulation techniques have been made in mixing and dispensing equipment, expendable molds, and kit-type packaging. The report lists resin suppliers, suppliers of formulated material, chemical structure of encapsulating resins and diluents, and 90 references from the literature.

SECTION H - ADHESIVES

1-623. THE EFFECT OF NUCLEAR RADIATION ON STRUCTURAL ADHESIVES. N. J. Broadway and S. Palinchak. Battelle Memorial Inst. Radiation Effects Information Center, Columbus, Ohio, REIC rept. no. 17. 1 Mar. 1961. 26p. illus. Contract: AF 33(616)-7375 (continuation of AF 33(616)-6564), Proj. no. 4458, Task no. 13008. 10 refs. A61-8577.

This report presents the state of the art on the effects of nuclear radiation on adhesives. It summarizes the radiation-effects information published up to 1961 for various adhesives based on organic materials. At present, information about the radiation stability of adhesives is available only for those adhesives developed for structural applications in aircraft and missiles. The adhesives were developed for metal bonding and are primarily epoxy- or phenolic-based compositions. Most of the available data were obtained by testing metal lap joints which had been irradiated at room temperature. Properties that have been examined include tensile-shear strength and bend strength. The data do not show what might happen if stress were applied to a specimen while it was being irradiated. In general it has been found that adhesives developed for high-temperature use, such as the phenolic-epoxy types, have better resistance to radiation as compared with thermoplastic and general-purpose types. Phenolic-epoxy adhesives, such as Shell 422J and Narmco 25-1, have excellent radiation stability at room temperature.

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They retain useful strength properties to a radiation-exposure dose of 10^{11} ergs $g^{-1}(C)$. For elevated temperatures (to 500°F), Adhesive 422J appears to be the best adhesive tested. It retains good shear strength when tested at 500°F after being exposed at room temperature to a radiation dose of 8.1×10^{10} ergs $g^{-1}(C)$. A vinylphenolic adhesive on a glass carrier, FM-47, and a modified nylon-phenolic adhesive, Cycleweld C-6, retain good shear strength at 10^{11} ergs $g^{-1}(C)$. These adhesives do not have the high-temperature characteristics of the phenolic-epoxy type. Most epoxy and nitrile rubber-phenolic adhesives show good adhesion at room temperature to 5×10^{10} ergs $g^{-1}(C)$. Neoprene-phenolic adhesives appear to be useful to 10^{10} ergs $g^{-1}(C)$. The rubber-phenolic adhesives are generally more flexible than the phenolic-epoxy type, but the bonded areas tend to creep under shear stress. In general, a filler improves the radiation stability of an adhesive, although in some cases at a sacrifice of the over-all shear strength. The curing agent and reactive diluent used in epoxy adhesives will also influence the radiation stability of the adhesive. Aromatic curing agents generally produce more radiation-resistant compositions than do the aliphatic curing agents.

SECTION I - WELDING AND BRAZING

- 1-624. BRAZING FOR HIGH-TEMPERATURE SERVICE.
H. E. Pattee and R. M. Evans.
Battelle Memorial Inst., Defense Metals Information Center,
Columbus, Ohio, DMIC Report 149. 21 Feb. 1961. 32p. illus.
Contract: AF 33(616)-7747. 118 refs. A61-6922.

This report summarizes many of the important developments in brazing for service temperatures in excess of 600°F. Heating methods, filler metals, atmospheres, fluxes, and deoxidizing agents are discussed as they affect the brazing of heat-resistant metals and alloys. Some attention is given to specific brazing applications.

- 1-625. REVIEW OF RECENT DEVELOPMENTS IN METALS JOINING.
J. J. Vagi, W. J. Lepkowski, et al.
Battelle Memorial Inst. Defense Metals Information Center,
Columbus, Ohio, DMIC memo 125. 1 Sept. 1961. 5p. 8 refs.
A61-8581.

This memorandum summarizes major developments in metals joining. Material received between 30 April and 20 July 1961 is included. The following topics are discussed: refractory metals; plasma welding of refractory metals; explosive welding; electroslog welding equipment; and adhesive bonding.

SECTION J - CHEMICAL AND PHYSICAL PROPERTIES OF MATERIALS

- 1-626. BIBLIOGRAPHY ON THE HIGH-TEMPERATURE CHEMISTRY AND PHYSICS OF MATERIALS IN THE CONDENSED STATE. International Union of Pure and Applied Chemistry Commission on High Temperatures Sub-Commission on Condensed States. October, November, and December 1959. 25 p. A61-7934.

Contents:

Devices for achieving high temperatures
 Devices for measuring and controlling high temperatures
 Devices for physical measurements at high temperatures
 Properties of refractory phases and systems studied at lower temperatures
 a) Metallic systems; b) Non-metallic systems; c) Mixed systems
 Properties and uses for refractory phases and systems at high temperatures
 a) Metallic systems; b) Non-metallic systems
 Properties of non-refractory phases and systems at high temperatures
 a) Metallic systems; b) Non-metallic systems
 Phase equilibria
 Reactions (physical and chemical) at high temperatures

- 1-627. BIBLIOGRAPHY ON THE HIGH-TEMPERATURE CHEMISTRY AND PHYSICS OF MATERIALS IN THE CONDENSED STATE. International Union of Pure and Applied Chemistry Commission on High Temperatures and Refractories Sub-Commission on Condensed States. January, February, and March, 1961. 32p. A61-7939.

Contents:

See Bibliography on the High-Temperature Chemistry and Physics of Materials in the Condensed State for October, November, and December 1959, A61-7939.

- 1-628. BIBLIOGRAPHY ON THE HIGH-TEMPERATURE CHEMISTRY AND PHYSICS OF MATERIALS IN THE CONDENSED STATE COVERING THE LITERATURE OF AUSTRIA, BELGIUM, FRANCE, JAPAN, SCANDINAVIA, UNITED STATES, AND U. S. S. R.
International Union of Pure and Applied Chemistry Commission on High Temperatures and Refractories Sub-Commission on Condensed States. January, February, and March, 1960. 32p. A61-7935.

Contents:

See Bibliography on the High-Temperature Chemistry and Physics of Materials in the Condensed State for October, November, and December 1959, A61-7934.

- 1-629. BIBLIOGRAPHY ON THE HIGH-TEMPERATURE CHEMISTRY AND PHYSICS OF MATERIALS IN THE CONDENSED STATE COVERING THE LITERATURE OF AUSTRIA, BELGIUM, FRANCE, GERMANY, JAPAN, SCANDINAVIA, UNITED STATES, AND U. S. S. R.
International Union of Pure and Applied Chemistry Commission on High Temperatures and Refractories Sub-Commission on Condensed States. April, May, and June, 1960. 38p. A61-7936.

Contents:

See Bibliography on the High-Temperature Chemistry and Physics of Materials in the Condensed State for October, November, and December 1959, A61-7934.

- 1-630. BIBLIOGRAPHY ON THE HIGH-TEMPERATURE CHEMISTRY AND PHYSICS OF MATERIALS IN THE CONDENSED STATE COVERING THE LITERATURE OF AUSTRALIA, BELGIUM, FRANCE, JAPAN, SCANDINAVIA, UNITED KINGDOM, UNITED STATES, AND U. S. S. R.
International Union of Pure and Applied Chemistry Commission on High Temperatures and Refractories Sub-Commission on Condensed States. July, August, and September, 1960.
34p. A61-7937.

Contents:

See Bibliography on the High-Temperature Chemistry and Physics of Materials in the Condensed State for October, November, and December 1959, A61-7934.

- 1-631. BIBLIOGRAPHY ON THE HIGH-TEMPERATURE CHEMISTRY AND PHYSICS OF MATERIALS IN THE CONDENSED STATE COVERING THE LITERATURE OF AUSTRALIA, AUSTRIA, CANADA, GERMANY, UNITED KINGDOM, UNITED STATES, AND U. S. S. R.
International Union of Pure and Applied Chemistry Commission on High Temperatures and Refractories Sub-Commission on Condensed States. October, November, and December 1960.
32p. A61-7938.

Contents:

See Bibliography on the High Temperature Chemistry and Physics of Materials in the Condensed State for October, November, and December 1959, A61-7934.

1-632. THE EFFECT OF NUCLEAR RADIATION ON SEMICONDUCTOR DEVICES. F. J. Reid.
Battelle Memorial Inst. Radiation Effects Information Center, Columbus, Ohio, REIC rept. no. 10 (Addendum). 15 July 1961. 36p. illus. Contract: AF 33(616)-7375 (continuation of AF 33(616)-6564), Proj. no. 1448, Task no. 13008. 36 refs. A61-8572, 1st Addendum.

This is the first addendum report to REIC Report No. 10, 30 April 1960, "The Effect of Nuclear Radiation on Semiconductor Devices". The report summarizes the radiation-effects information on permanent damage introduced in various transistor- and diode-type devices for which data have been published since January 1960. Information on transient radiation effects has not been included, as these data are summarized in REIC Report No. 6-C "The Effects of Nuclear Weapon Bursts and Simulated Bursts on Electronic Components," Secret, Restricted Data. Proton and electron effects on semiconductor materials and devices will be the subject of a future REIC Memorandum. Data are presented on investigations of standard silicon and germanium transistors, diodes, rectifiers, and such devices as unipolar transistors, Esaki diodes, and SiC, GaP, and selenium rectifiers. The report is intended to be sufficiently inclusive to make it valuable as a guide on effects which can be anticipated from nuclear radiation on electronic

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components utilizing semiconductor devices. During irradiation the current gain is decreased because of changes in volume recombination in the material. Low alpha cutoff frequency transistor types are more easily damaged by nuclear radiation than are higher alpha cutoff frequency units of the same material and structure. Germanium transistors are less sensitive to fast-neutron damage than are silicon transistors. Diffused-junction structures are less sensitive than are alloyed-junction structures.

- 1-633. THE PROPERTIES OF BORON. D. N. Williams.
Battelle Memorial Inst., Defense Metals Information Center,
Columbus, Ohio. DMIC Memo 41. 4 Jan. 1960. 8p. 19 refs.
A61-6455.

There has long been interest in the use of boron as a structural material, generated by its low density, high melting point, high hardness, high elastic modulus and relatively high specific heat. Research to date has produced discouraging results; the material shatters at low impact, has no ductility and only very poor thermal shock resistance. This report is a collection of available authentic data about the method of production, physical properties and mechanical properties of boron.

- 1-634. RESEARCH IN PHYSICAL AND CHEMICAL PRINCIPLES
AFFECTING HIGH-TEMPERATURE MATERIALS FOR ROCKET
NOZZLES. Robert Lowrie. Semiannual Progress Report,
Union Carbide Research Inst., Tarrytown, N. Y. and Parma
Research Center, Cleveland, Ohio, Labs. of Union Carbide
Corp. 30 June 1961. 69p. illus. Contract:
DA-30-069-ORD-2787. A61-8603.

Experimental data, much of it still of a preliminary nature, has been obtained during this reporting period for a few refractory compounds as well as for carbon, tungsten, and other materials selected for special reasons. New equipment has been employed for studying gas-solid reactions, for obtaining high-temperature x-ray diffraction data, and for vaporization and matrix isolation of carbon; other equipment is being assembled for tensile creep testing at high temperatures, and for measurement of Hall effect and magnetoresistance. Mass spectroscopy has been used to measure heats of vaporization and formation for TiB_2 . The values obtained for systems in several different regions of the phase diagram range as follows: $\Delta H_{298}^V = 428.4$ to 431.4 kcal/mole and $\Delta H_{298}^F = -50.7$ to -53.7 kcal/mole. Values for the heat of vaporization of aluminum from AlN obtained by mass spectroscopy have approached to within 8 kcal/mole of the value calculated from a calorimetric heat-of-formation result. Matrices of carbon vapor in argon have been prepared and their absorption spectra studied. (cont.)

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A strong doublet at $2036\text{--}2040\text{ cm}^{-1}$ appears to be caused by the C_3 molecule. Studies of the reactions of graphite with nitrogen have shown that there is essentially no reaction with molecular nitrogen up to 2200°C but that above 1350°C atomic nitrogen reacts with graphite to form cyanogen. The rate of cyanogen formation is not time-dependent and does not depend strongly upon temperature up to 1830°C . HCN is produced if there is adventitious hydrogen present in the system. The reaction of hydrogen with graphite has been studied under both static and kinetic conditions. In both cases the major products are acetylene and methane with small amounts of ethane and ethylene. The activation energy for the formation of acetylene is 74 kcal/mole for the range $1895\text{--}2000^\circ\text{C}$ but 210 kcal/mole from $2130\text{--}2370^\circ\text{C}$. This may be the result of a gas-phase reaction at the higher temperatures. Increasing the temperature in the range $2000\text{--}2500^\circ\text{C}$ at constant hydrogen flow rate increases the amount of product formed per minute and per mole of H_2 , and also increases the percentage of higher hydrocarbons. The thermal conductivities of graphite foams have been measured, and a model has been used successfully to describe the properties of these foams. The rectangular bar method and the Powell-Schofield method of measuring thermal conductivity have been shown to agree for a graphite foam with 84% porosity. The electrical resistivities and thermal conductivities of US, CeN, and UN-CeN have been measured as 0.5, 0.3 and 1.1 milliohm-cm (cont.)

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and 0.1, 0.05, and $0.03\text{ watt cm}^{-1}\text{ deg}^{-1}$ respectively in the range $800\text{--}1200^\circ\text{C}$. Studies of the creep in bending of MgO single-crystal specimens from $1450\text{--}1700^\circ\text{C}$ show that the creep rate is proportional to the load raised to a power which varies from the 4th to the 7th depending upon the temperature. Measurements have been made of the velocities of compressional and shear waves in polycrystalline tungsten up to 1800° and 1280°C respectively. The Young's modulus of tungsten decreases smoothly with temperature, but the shear modulus shows an anomaly in the range $654\text{--}774^\circ\text{C}$. There is also a large increase in the attenuation of the shear wave between 654 and 774°C and again just below 1280°C . From X-ray diffraction line shifts and intensity data the thermal expansion and mean lattice-vibration amplitudes of tungsten have been obtained up to 1800°C . Powders of refractory compounds have been significantly purified by heating in a vacuum at temperatures up to 2000°C . TiC, ZrC, and HfC have been produced to 99-99.5% purity with atomic ratios of combined carbon to metal of 0.96 to 0.98. Powdered diborides of titanium, zirconium, and hafnium have also been purified by heating in vacuum. Tantalum carbide and columbium carbide have been made with 99.5% purity even before vacuum treatment.

- 1-635. THERMOPHYSICAL PROPERTIES OF SOLID MATERIALS. VOLUME I-ELEMENTS. (MELTING TEMPERATURE ABOVE 1000°F). Alexander Goldsmith, Thomas E. Waterman, and Harry J. Hirschhorn. Illinois Inst. of Tech., Chicago. Armour Research Foundation, WADC TR 58-476, vol. 1. (Revised Edition). Aug. 1960. Contract: AF 33(616)-5212, Proj. no. 7381. AD 247 193. A61-1125, vol. 1.

Thermophysical property data, and their variation with temperature, are presented for a great number of solid materials, based on literature published during the period 1940-1957. Each reported value is shown and annotated, and recommended "most probable value" curves are given. Materials covered include elements, alloys, ceramics, cermets, inter-metallics, polymerics, and composite materials. Except for materials in the last two categories, only those melting above 1000°F are included. Properties covered include the following: Melting point, density, latent heats, specific heat, thermal conductivity, thermal diffusivity, emissivity, reflectivity, thermal expansion, vapor pressure, and electric resistivity. This volume treats the thermodynamics property data of elements.

- 1-636. THERMOPHYSICAL PROPERTIES OF SOLID MATERIALS. VOLUME II-ALLOYS. (MELTING TEMPERATURE ABOVE 1000°F). Alexander Goldsmith, Harry J. Hirschhorn, and Thomas E. Waterman. Illinois Inst. of Tech., Chicago. Armour Research Foundation, WADC TR 58-476, vol. 2. (Revised Edition). Nov. 1960. 608p. illus. Contract: AF 33(616)-5212, Proj. 7381, Task no. 73812. A61-1125, vol. 2.

Thermophysical property data, and their variation with temperature, are presented for a great number of solid materials, based on literature published during the period 1940-57. Each reported value is shown and annotated, and recommended "most probable value" curves are given. Materials covered include elements, alloys, ceramics, cermets, inter-metallics, polymerics, and composite materials. Except for materials in the last two categories, only those melting above 1000°F are included. Properties covered include the following: Melting point, density, latent heats, specific heat, thermal conductivity, thermal diffusivity, emissivity, reflectivity, thermal expansion, vapor pressure, and electric resistivity. This volume treats the thermodynamic properties of alloys including iron, copper, nickel, cobalt, refractory metal-base and light metal alloys.

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